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MINISTRY OF AVIATION

D1/57

DAMAGE BY NUCLEAR WEAPONS

A MANUAL OF BASIC TARGET RESPONSE DATA

SECURITY NOTE

This document has been issued in parts over an extended period and much of the earlier material now has a lower classification than it carried at the time of issue. Notwithstanding the grading shown on individual sheets dated earlier than March, 1959, the whole of the contents are now covered by the grading CONFIDENTIAL DISCREET.

Prepared by the Director General of Atomic Weapons
Ministry of Aviation.

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DAMAGE BY NUCLEAR WEAPONS

Amendment Certificate.

Amendment Number	List Date	Amendments Made By	Date
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9.8.3. Indirect Blast Injury: Casualty Estimates

Most blast casualties in cities are caused by damage to buildings. The occupants may be crushed, trapped, or struck by building materials projected by the blast. The number of casualties caused by a nuclear weapon will, of course, be dependent on the degree of protection afforded by the buildings and upon the extent to which advantage has been taken of such protection. For these reasons estimates of casualties cannot be expected to be more than rough guides to be used for Civil Defence planning.

Casualty figures from Hiroshima and Nagaski cannot be directly applied to Western conditions because of differences in house construction, and because the populations of these cities were not aware of the dangers to which they were exposed. But a method has been devised (1) in which the estimates of damage to British houses, (given by the British Mission to Japan), are used in conjunction with H.E. data from the last war on casualty rates in damaged houses to provide casualty rates for nuclear weapons.

The H.E. material was, of course, based on the high standard of rescue possible in the last war, and it has been necessary to adjust the casualty rates, since organised rescue of trapped occupants from the more severely damaged buildings will hardly be possible in nuclear war. The adjusted rates are given in Table I below, and can be used to derive casualty estimates.

TABLE I. CASUALTY RATES FOR OCCUPANTS OF BRITISH HOUSES

DAMAGE CATEGORY	KILLED	SERIOUSLY INJURED	LIGHTLY INJURED
A (> 15 p.s.i.)	80%	5%	1%
B (15-7½ p.s.i.)	40%	7%	5%
Cb(7½-3 p.s.i.)	-	9%	6%
Ca(3-1¾ p.s.i.)	-	2%	2%
D (1¾-1 p.s.i.)	-	-	-

Note: (1) these casualty rates are related to blast effects only.
(2) typical 2-storey British houses assumed, with 9" or 11" brick walls.
(3) assumed that whole population is in such houses, taking best advantage of protection afforded.
(4) for definitions of damage categories see Section 9.1.3.

The pressure ranges for the various categories of damage given in Table I may be used in conjunction with the appropriate blast pressure curves to derive the extent of damage for any power of nuclear weapon.

American analysis of somewhat limited Japanese data for reinforced concrete structures suggests that on account of their much greater blast resistance, collapse is associated with almost 100% fatality. Moderate damage may be associated with 10% dead, 15% seriously and 20% lightly injured and light damage with 5%, 5% and 15% respectively. The corresponding damage distances are given in Section 9.2.2. Figure 2, and

Section 9.2.6, Figure 2. To make a good estimate of casualty production in other structures it is necessary to consider the type of structural damage that occurs and the characteristics of the resultant missiles. Glass breakage extends to considerably greater ranges than almost any other structural damage, and may be expected to produce large numbers of casualties at ranges where personnel are relatively safe from other effects, particularly for an unwarned population.

American estimates are that in cases of severe damage some 60% of the survivors may have to be extricated by rescue squads. Without rescue they may become fire or asphyxiation casualties, or in some cases be subjected to lethal doses of residual radiation.

A major cause of personnel casualties in exposed situations is flying missiles. These missiles have low velocities and many crushing injuries may be expected, in contrast to penetrating wounds caused by high velocity missiles. The missile density and characteristics are largely a function of the target. Where the target area is relatively clean and there is little material present subject to fragmentation and displacement, fewer injuries from missiles are expected in the open than from debris within structures at comparable distances. When the target complex presents many possible sources of missiles, this cannot be the case. Personnel in a prone position are less likely to be struck by flying missiles than those who remain standing. Those who succeed in getting into bunkers, foxholes, or in defilade, probably achieve almost complete protection from the flying missile hazard.

Personnel in vehicles may be injured as the result of the response of the vehicle to the blast forces. Padding where applicable, and the use of safety belts, helmets and harnesses virtually eliminates this source of casualties, at least within armoured vehicles. In the absence of these protective devices, serious lacerations may result from impact with sharp projections within the vehicle interior, but these vary greatly among different vehicles and at different positions within the same vehicle. Comparative numbers of casualties are almost impossible to assess in this respect, due to the many variables which are involved in the problem.

References

(1) Civil Defence Joint Planning Staff Paper C.D.J.P.S.(E.A.)(48)14 (Revised).

(2) Manual on the Effects of Atomic Weapons. A.W.R.E. (Secret/Atomic)

(3) Capabilities of Atomic Weapons A.F.S.W.P. (Secret/Atomic)

CHAPTER 8 - BIOLOGICAL EFFECTS OF BLAST

This Chapter is to be issued later.

The reader is meanwhile referred to Chapter 9, Sections 9.8. and 9.9. for general data, and to references (1) and (2) for summaries of British and American work.

References.

(1) Recent observations on the effects of blast on animals. August 1957. Professor Sir Solly Zuckerman. Ministry of Defence AWEC/P(57)38.(Confidential)

(2) The biological effects of blast.. A critical review. September 1954. Clayton S White. M.D. Lovelace Foundation for Medical Education and Researoh, Albuquerque, New Mexico. Report T.I.D.5251. (Confidential.Restricted Data.)

(1) The general character of the blast wave which struck the sites close in to Ground Zero was unlike the wave from conventional charges, and was influenced to an unknown extent by the earth walls which formed an indispensable part of the experimental layout.

(2) Even when the shape of the wave became more "normal" it still did not show the typical extremely rapid rise to peak pressure.

It must therefore be accepted that other types of weapons and other sites which might alter the shape of the incident wave might also influence the results obtained. Nevertheless, taking into account how much the effects of radiation and displacement contribute to the total lethality of the weapons, it is clear that the direct impact of the blast wave on human beings is not an important hazard.

8.3 Injuries caused by translational motion

An investigation into the displacement of personnel by the free air blast wave from Round 1 of Operation Buffalo is reported in Reference (2). It is noted in this report that the only previous enquiry into the problem was a theoretical study by Liston (Reference (3)), who calculated that a man weighing 12 stone standing 1300 yards from a 20 KT weapon would be displaced 20 ft. and suffer severe injuries. A like person at 2000 yards would be displaced 4 ft. and uninjured. Liston also predicted that a man lying prone at 1300 yards would be quite safe since his displacement would be insignificant. These predictions were checked by the experiments performed at Operation Buffalo.

Two modes of injury by the blast wind were envisaged for investigation:-

(1) If exposed to a sufficiently strong wind men would move bodily and receive injuries on striking fixed objects or the ground.

(2) The wind may cause sudden jerking movements of the limbs relative to the trunk. If sufficiently violent, these movements would cause dislocation of the joints or break bones.

The method of investigation was to use 30 articulated dummy men clad in battle dress and set out before the explosion of a weapon of approximately 15 KT, detonated on a tower. The dummies were set out in six orientations to the explosion, and each orientation was displayed at five ranges.

Description of Dummy Men

The dummies were designed to resemble men ballistically, to simulate as far as possible with inanimate objects the interaction between man and the blast wave. The model chosen for the experiments had been designed and developed by R.A.E., Farnborough (Reference (4)) for studies of seat ejection and restraint harnesses (Reference (5)). Consisting basically of mild steel, with cannisters for limb segments, the dummies were manufactured so that the total weight and segment weights and the centres of gravity of the various limbs, trunk and head were all appropriate for a 6 ft. man weighing 175 lb. ($12\frac{1}{2}$ stone). The metal parts were covered with rubber foam. The limbs were articulated at hips, knees, shoulders and elbows by $\frac{1}{4}$ inch mild steel tongue and groove joints, swivelling on $\frac{1}{2}$ inch mild steel bolts. There were cavities in the chest compartment and abdomen for accelerometers.

The dummies were dressed in worn service uniform: khaki shirt, battledress, socks and boots. This was specified because clothing obviously influences the drag coefficient of man exposed to the blast wave. It has been reported that clothing was torn away completely from survivors at Hiroshima and Nagasaki.

The effects of the forces acting on the dummies were followed by estimating the displacement of the dummies, and from accelerometer and cinematograph records where these were available. Since the effects would depend upon friction and upon the area exposed to the weapon, six postures were chosen. Standing, crouching and lying were selected as representing three stages in evasive action. Each of these positions was duplicated, facing (or head towards), and sideways-on to the weapon. Each of these six postures was exposed at five ranges, as shown in Table 1 below. The presented areas of the dummies are given in Table 2.

TABLE 1

Layout of Dummies Clad in Battledress

Site No.	Range from G.Z. ft.	Posture of Dummy					
		Prone		Crouching		Standing	
		Facing	Side-ways	Facing	Side-ways	Facing	Side-ways
1	1840	+	+				
2	2056	+	+				
3	2200	+	+	+	+		
4	2390	+	+	+	+	+	+
5	2656	+	+	+	+	+	+
6	3110			+	+	+	+
7	3900			+	+	+	+
8	6000					+	+

TABLE 2

Areas presented by the dummies towards the explosion

Posture	Area in square feet	
	Facing explosion	Sideways-on
Prone	1	5
Crouching	4	5
Standing	10	5

Results

The results in terms of displacements of the dummies, together with the estimated pressures which occurred at the various ranges are given in Table 3.

TABLE 3

Displacements Classified According to Drag Pressure Posture and Orientation

Range from G.Z. ft.	Drag Pressure p.s.i.	Over-pressure p.s.i.	Posture					
			Prone		Crouching		Standing	
			F ft.	S ft.	F ft.	S ft.	F ft.	S ft.
1840	7.4	18/	42	66	-	-	-	-
2056	4.4	14.5	2.5	69	-	-	-	-
2200	3.7	12	2	20	15	39	-	-
2390	2.7	10	1	8*	16	18	35	20
2656	1.9	8.5	1	24	9	9	30	16
3110	1	6.4	-	-	6	9	16	10
3900	0.43	4.3	-	-	1	3(4)	4(7)	3(6)
6000	0.11	2.4	-	-	-	-	2(5)	0

*This dummy was sited on firm rocky ground. All others were sited on soft ground.

/Multiple peaks in overpressure record.

In certain cases in Table 3 additional information is given in parenthesis: these figures represent the actual displacements of the centres of gravity, which were corrected for displacement through the final toppling over from the standing or crouching position.

Electrical circuit failure prevented time resolution of accelerometer records and only peak accelerations in the vertical, lateral and longitudinal planes became available for analysis. The peak accelerations in the plane of initial displacements for the instrumented dummies are shown in Table 4.

TABLE 4.

Maximal Positive Accelerations Recorded in the Planes of Initial Displacement of the Dummy Men Exposed in the Open

Range feet	Posture and Plane					
	Prone		Crouching		Standing	
	Facing Vertical g	Sideways Lateral g	Facing Vertical g	Sideways Lateral g	Facing Longitudinal g	Sideways Lateral g
1840	14	14				
2200	9	12	7	19		
2390					26	24
2656	4	7	11	13		
3110					*	55
3900			6	7		
6000					13	3

*Burned out.

It was presumed that the maximum decelerations recorded occurred at the terminal collision with the ground. These results should give some indication of the damage sustained, and are quoted in Table 5.

TABLE 5

Maximal Decelerations Derived from Accelerometer Results Classified According to Range Posture and Orientation

Range Feet	Posture					
	Prone		Crouching		Standing	
	Facing g	Sideways g	Facing g	Sideways g	Facing g	Sideways g
1840	18	35				
2200	18	17	17	15		
2390					53	11
2656	12	17	26	11		
3110					*	22
3900			0	26		
6000					16	5

*Burned out.

Records were also made of joint changes and displacement of steel helmets.

It is noted from Table 3 that for any drag pressure, the displacement of the dummies oriented sideways-on is of the same order, irrespective of posture. This implies that friction with the ground did not impede take-off of the prone and crouching dummies.

From (i) the drag pressure, (ii) the surface area presented to the explosion, and (iii) the duration of the blast wind, it is possible to calculate impulse. This is proportional to the product of (i) x (ii) x (iii).

Using the figures for presented area given in Table 2 above, together with data for drag pressures and wind durations, a curve for the relationship between impulse and displacement has been constructed. Figure 1 shows this relationship. This solid line is the regression curve calculated to fit the results. It has the form:-

$$\text{displacement (feet)} = \frac{(A \times P \times T)^{1.5}}{1660}$$

where A = presented area (in^2)

P = peak drag pressure (p.s.i.),

T = duration of positive phase (sec.)

The dotted lines in Figure 1 show the 95% confidence limits based on the fore-going data.

Regarding the accelerometer data, there was firm correlation between initial acceleration recorded and the displacement suffered. The correlation between displacement and maximal decelerations is poor, and no

correlation can be recognized between deceleration and severity of damage to the dummy. It is apparent therefore that while some displacement must occur to cause injury, injury or damage depends more upon the detailed nature of the terminal collision than upon the magnitude of the displacement or rapidity of deceleration.

Conclusions

In attempting to deduce what would have been the fate of soldiers exposed in the same way as the dummies the authors of Reference (2) conclude that:-

(1) All such soldiers would have suffered severe flash burns on exposed skin.

(2) All such soldiers within 3500 ft. (i.e. Sites No.1-6) would have suffered serious, lethal, radiation illness.

(3) All soldiers beyond 4000 ft. in open country would have suffered little or no injury from blast displacement per se.

(4) Soldiers at ranges of less than 2250 ft. would probably have suffered moderate to very severe injuries from blast displacement per se. (Three metal limbs were disarticulated in this zone).

(5) The severity of injury would have been roughly proportional to the surface area presented to the blast wave. Thus crouching and standing dummies show greater displacement than prone dummies at similar ranges. Similarly prone dummies exposed sideways-on to the explosion suffered greater displacement than prone dummies with heads towards Ground Zero.

In view of the observed displacement of steel helmets it is further concluded that wearing the retaining strap of a steel helmet under the chin is inadvisable, and that steel helmets might possibly become dangerous missiles, especially in confined spaces.

Some further trials with dummy men were performed at Operation Antler and are fully reported in Reference (6). These trials were carried out out for Antler Round 2 (about 5 KT) and Round 3 (about 25 KT) on similar lines to the tests at Buffalo, although in the Antler tests some additional dummies were exposed in Daimler Scout Cars (Round 2) and Champ Vehicles (Round 3). The following conclusions are given:-

(a) The information obtained on the displacement of dummies by blast confirms and amplifies that obtained from Operation Buffalo.

(b) Damage to dummies was more severe in the area affected by the precursor blast wave of the balloon burst weapon of about 25 KT total yield, than would have been expected from results at similar peak static overpressures obtained from the tower burst weapon of about 5 KT total yield where no precursor was present. (It should be remembered that precursor conditions only occur when the blast is likely to be very severe in any case).

(c) The conclusion reached after Operation Buffalo, that the best position for a man caught in the open when struck by a blast wave is prone and facing the blast, was confirmed.

(d) The wearing of a steel helmet with the strap under the chin is likely to lead to neck injury if the wearer is struck by a blast wave of peak static overpressure greater than 4 p.s.i.

References

(1) Krohn P.L. and J. McGregor, A.W.R.E. Report T3/58
"The Physiological Effects of Long Duration Blast Waves."
(Confidential)

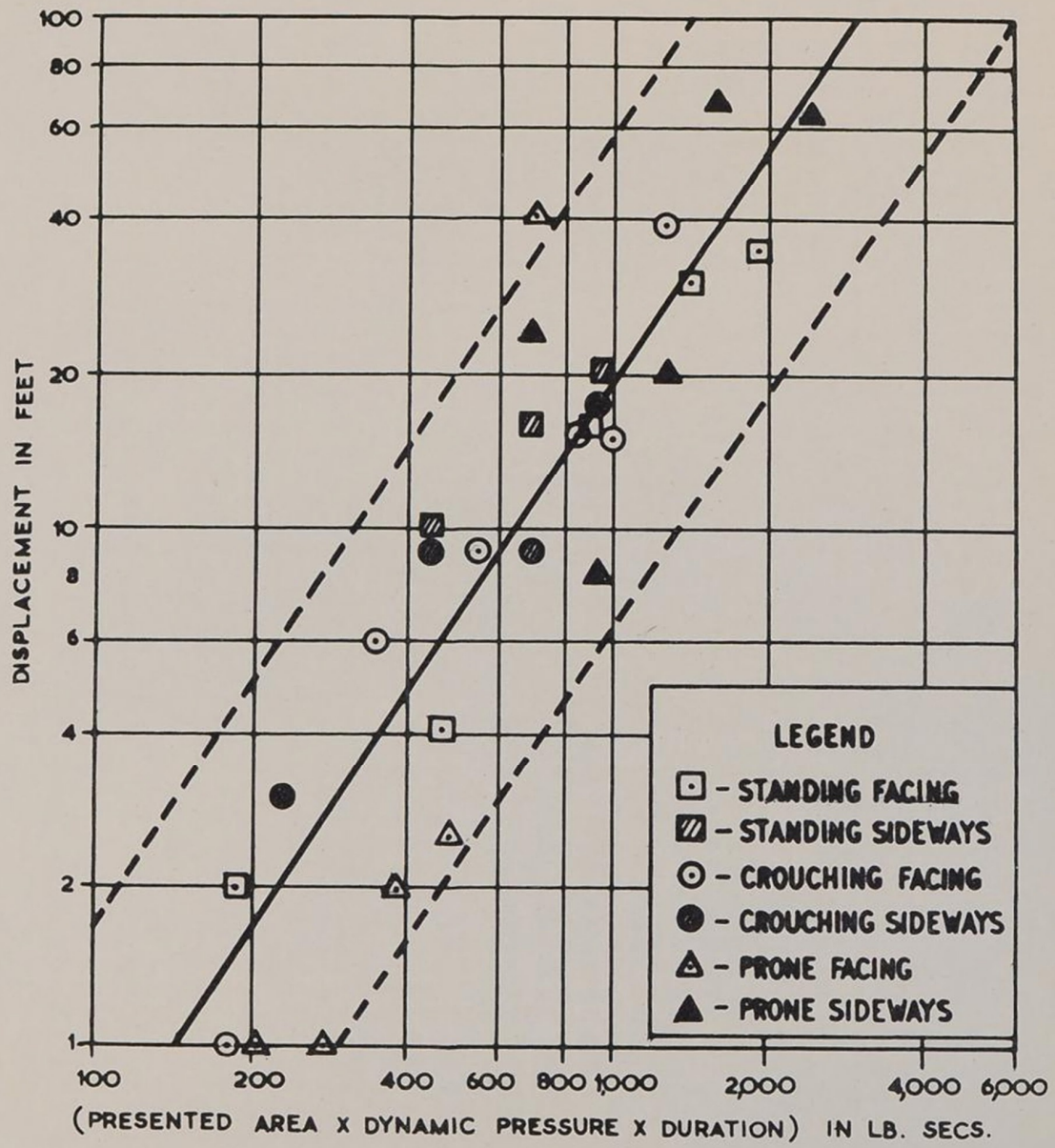
(2) Butterfield, W.J.H., E.G. Hardy and E.R. Drake Seager, A.W.R.E. Report T2/59.
"The Effects of Blast on Dummy Men Exposed in the Open"
(Confidential)

(3) Liston, R.H.A. A.R.E. Report 1/48, Part 6.
"The Kinematic Effect of Blast on a Man in the Open."

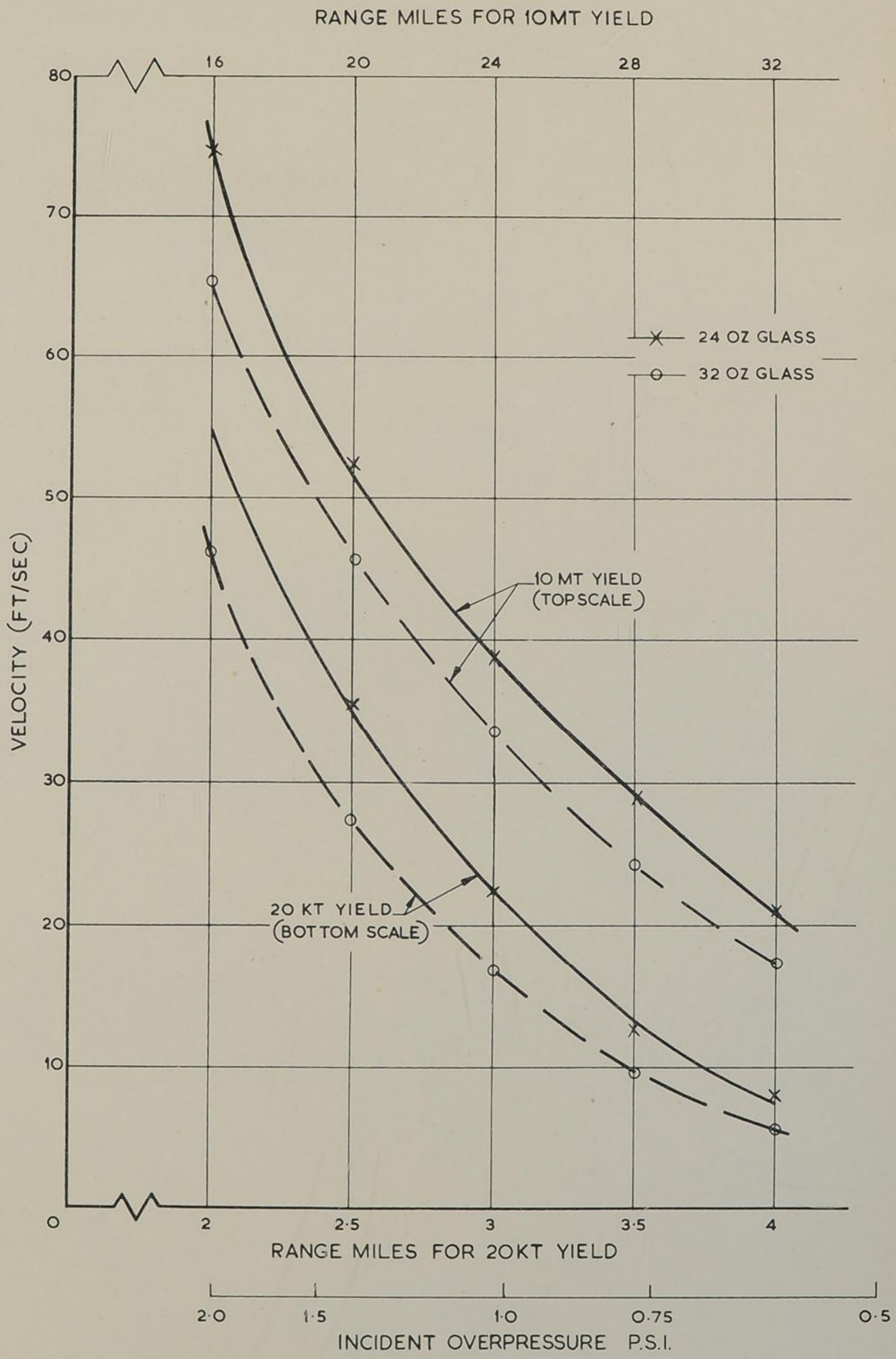
(4) Lovell, G., R.A.E. Technical Note Mech.Eng. No.176 (May, 1954).

(5) Latham, F., "Linear Deceleration Studies and Human Tolerance", Clinical Science, 17, 121(1958).

(6) Martin, A.R.F., A.W.R.E. Report T6/59, "The Effects of Blast on Dummies and Scout Cars."
(Confidential)



THE RELATIONSHIP BETWEEN DISPLACEMENT
AND (AREA PRESENTED X DYNAMIC PRESSURE X DURATION)



VELOCITY OF GLASS FRAGMENTS 10 FEET FROM WINDOW

5.2.4. Window Glass

It may be assumed that glass under shock remains elastic up to failure. The elastic properties vary with the type of glass and heat treatment, but Kaye and Laby (1) give the following values:-

Young's Modulus $E = 7$ to 10×10^6 p.s.i.

Tensile Strength $T = 4{,}000$ to $13{,}000$ p.s.i.

It is recommended that for window glass $E = 8 \times 10^6$ p.s.i., $T = 5{,}000$ p.s.i. should be used.

In an experiment at B.R.L. (2) a number of glazing materials were used to close the end of the 24 inches diameter shock tube. The test windows were 16 inches square and were subjected to the reflection pressure of the shock wave in the tube for a time corresponding to the positive duration of the blast from a 20KT atomic bomb. The incident overpressure at which the windows just failed was determined.

The results are given below:-

Material	Incident Overpressure (p.s.i.)
24 oz (3 mm) window glass	0.75*
44 oz (5.5 mm) window glass	1.0
$\frac{1}{4}$ inch plastic coated glass	1.5
$\frac{1}{4}$ inch safety glass	1.5
$\frac{1}{4}$ inch wire glass	1.0*
$\frac{1}{4}$ inch tempered glass	7.0

* Confirmed by recent British trials. Reference (3)

The maximum pressure which a window will withstand depends mainly on the maximum stress produced, usually at the edges. It is therefore very dependent on the method of mounting of the glass and on the size of the window. It will, for example, become less as the putty ages and hardens, so that test results with new putty are of uncertain significance. Experience with bangs from supersonic aircraft suggests that practical values as low as 0.1 and 0.01 p.s.i. may be not uncommon, and values down to 0.007 p.s.i. have been observed. Using suitable precautions windows at Foulness are repeatedly subjected to pressure of about 0.1 p.s.i. without harm. The effects of an immediately preceding heat flash are not known. Section 7.1 gives information concerning the velocities of glass fragments.

References

(1) Kaye, G.W.C. and T.H. Laby, "Tables of Physical and Chemical Constants", Eleventh edition, Longmans, London (1956).

(2) Ballistics Research Laboratory Memo. Report No.626 (1952)

(3) A.W.R.E. Report No.T 18/57 (Confidential)

TABLE I - Damage Criteria for Light Earth Covered Structures

Structure	Damage	Peak Over-pressures (psi)	Remarks
Light steel arch surface shelter with 3 ft. of earth cover over crown. (10-0.141 inch gauge corrugated steel with a span of 20 to 25 ft.)	Severe	25-35	Collapse
	Moderate	20-25	Slight permanent deformation of arch
	Light	10-15	Deformation of end walls, possible entrance-door damage.
Light reinforced concrete surface or underground shelter with 3 ft. minimum earth cover (2 to 3 inch thick panels with beams spaced at 4 ft. centres).	Severe	25-35	Collapse
	Moderate	15-30	Deformation, severe cracking and spalling of panels
	Light	10-15	Cracking of panels, possible entrance door damage

Note. - A spread in peak overpressures for various degrees of damage is indicated to allow for differences in structural design, soil conditions, shape of earth mound, and orientation with respect to the blast wave. For defensive planning use the lower values.

9.3.2. Field Fortifications and Defences - Air blast is the controlling damage parameter for destruction of field fortifications such as unreinforced trenches and foxholes, revetted positions, and covered field shelters.

Un-reinforced Fortifications - The resistance of unrevetted trenches and foxholes to air blast is primarily dependent upon the soil characteristics, particularly the cohesive qualities of the soil.

Revetments - Revetted emplacements resist collapse at considerably greater overpressures than unrevetted emplacements. Light revetting materials such as chicken wire and burlap, or paste board, corrugated sheet metal, or plywood, when well supported, are fairly resistant to air blast. Light timber revetments are more resistant to air blast.

Overhead Cover - Covered fortifications that have their cover flush with ground level are subject primarily to downward pressures on the roof, whereas those fortifications having their cover above ground level are subjected also to drag loading,which tends to remove loose earth and disarrange and remove the cover structures. Entrances are usually the weakest point of blast resistance.

Other Damage Mechanisms - Severe air blast damage to revetted field fortifications occurs at ranges where damage due to direct ground shock and cratering alone is insignificant. However, for unrevetted foxholes and trenches in most soils, the direct ground shock produced by an underground burst contributes somewhat to the collapse. Superficial scorching of the wooden portions of field fortifications may also occur.

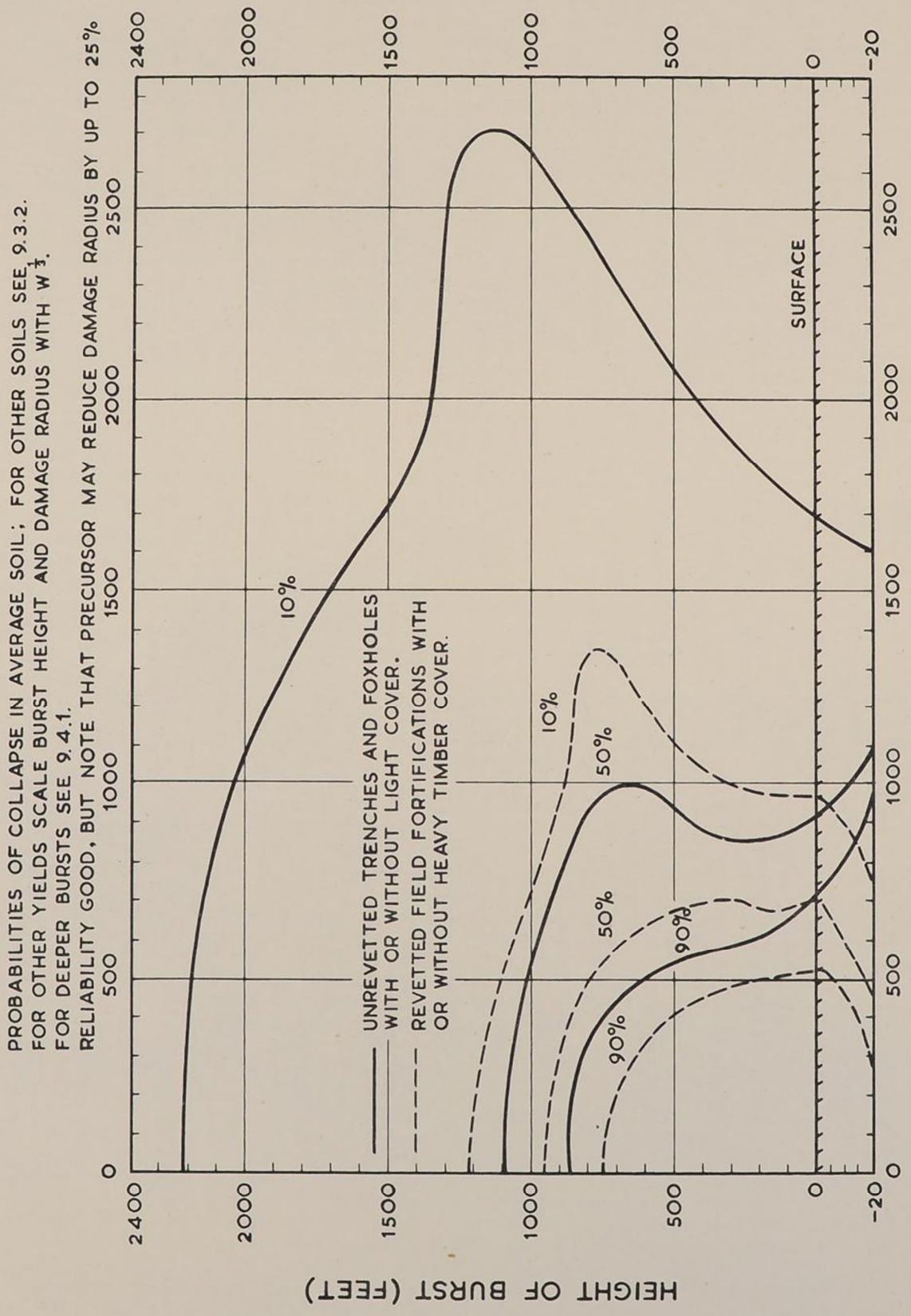
Damage Computations - The criteria for air blast damage are given as probabilities of causing collapse of the fortification. Figure 1 gives the height of burst versus ground range from a 1 KT burst for damage in average soil to unrevetted trenches and foxholes with or without light cover, and rivetted field fortifications with or without heavy timber cover. The given damage ranges are reduced in cohesive soils and increased in cohesion soils. If a precursor is expected, ranges may be as much as 25% less than those shown.

To obtain heights of burst and distances for yields other than 1 KT, use the scaling law -

$$\frac{d_1}{d_2} = \frac{W_1^{\frac{1}{3}}}{W_2^{\frac{1}{3}}} = \frac{h_1}{h_2}$$

Where d_1 and h_1 are ground distance and height of burst for yield W_1 KT and d_2 and h_2 are ground distance and height of burst for yield W_2 KT.

NOTE: For damage to barbed wire defences see Section 9.4.1.



DAMAGE TO FIELD DEFENCES. 1 KT.

9.4. Military Field Equipment

9.4.1. Introduction

Damage Mechanisms - Military field equipment targets are for the most part small, rugged, and free to move, and as such are primarily sensitive to the drag forces associated with the blast wave. Under some circumstances however, such as when items are shielded from drag forces or lie in the early regular reflection region, crushing by peak blast wave overpressures may be important. The drag forces tend to displace and to tumble targets of this type, and in the process, to damage them. Direct thermal damage to field equipment in general is not of importance; however, for certain items such as POL dumps, fire effects are important and are treated below. Secondary fire hazards from vegetation are not considered in this section.

Damage levels and definitions - Many factors must be considered in the selection of damage criteria for military field equipment targets. Among these are orientation of the item of equipment with respect to ground zero, orientation of the blast wave with respect to surface, i.e. whether the item is in the regular or in the Mach. region; shielding effects; the nature of the particulate matter in the blast wave; the presence or lack of flammable materials; the magnitude of the blast forces.

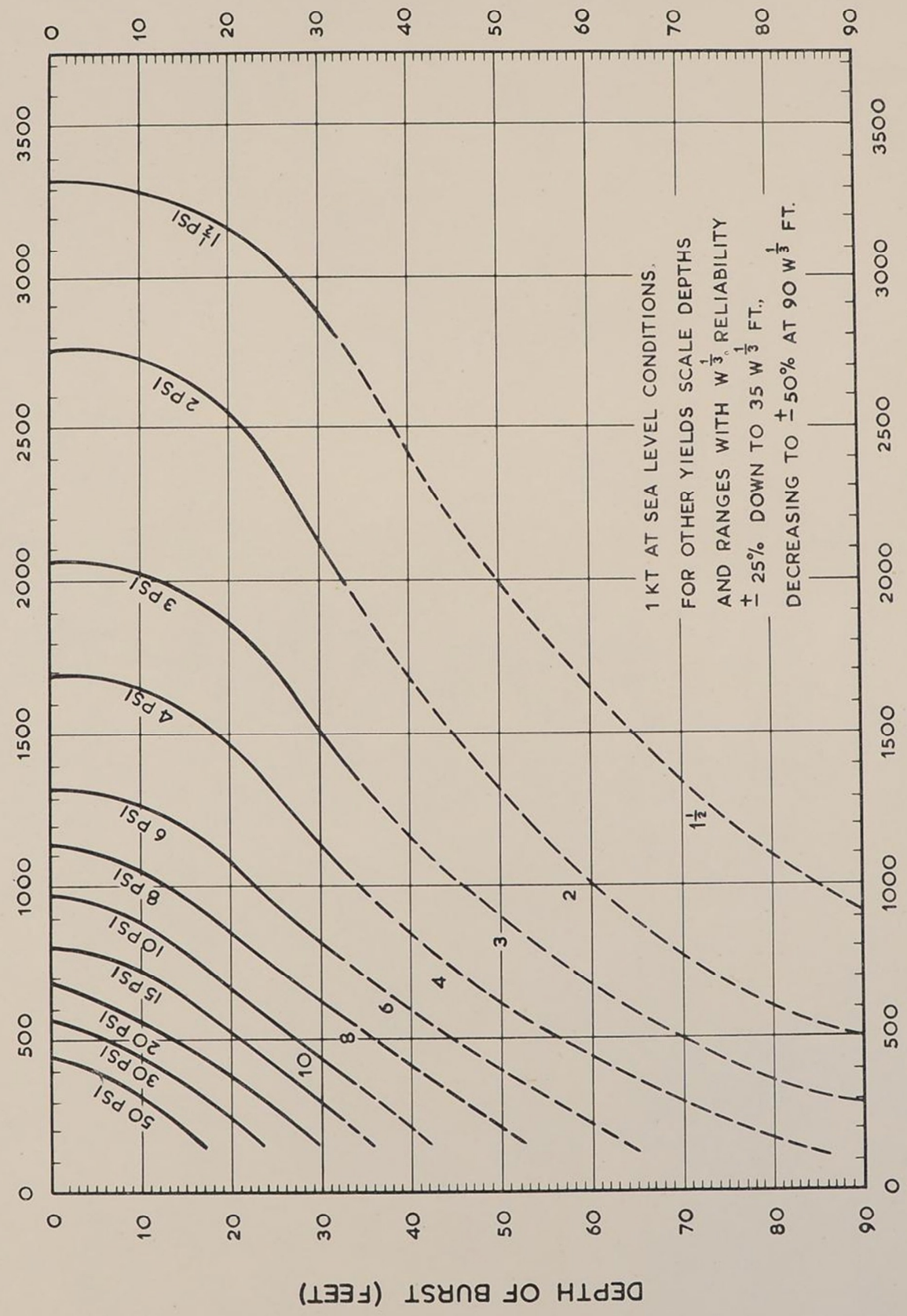
To simplify the presentation of damage criteria for blast effects in the following paragraphs, a height of burst versus ground range method of presentation for various levels of damage is used. The levels of damage are defined as follows:-

Severe — that damage which is sufficient to prevent the accomplishment of any useful military function and the repair of which is essentially important without removal to a major repair facility.

Moderate — that damage which is sufficient to prevent any military use until some repairs are effected.

Light — that damage which does not seriously interfere with immediate military operations but necessitates some repair to restore the item to complete military usefulness.

Damage Probabilities - Specific examples of the types of damage associated with a given level of damage are included for each major item of equipment. Distances shown for moderate damage are the distances for which the probability of the damage occurring is 50%, and in some cases where the data permits, 10%. Distances shown for severe damage are those for which the probability of damage occurring is 50%, and in some cases where sufficient data is available, 90% and 10%. For light damage the distances are those for which the probability of damage is 10%. It is intended that the light damage curve and the moderate curve for 10% probability should be used to indicate approximate limits of damage, and thus may be of value in determining how close equipment may be placed to friendly bursts without endangering the combat usefulness of that equipment. It is assumed that for all damage curves, unless stated otherwise, that the items of equipment are oriented in a random fashion with respect to ground zero and lie unshielded on fairly level terrain. A discussion on shielding effects is given below.

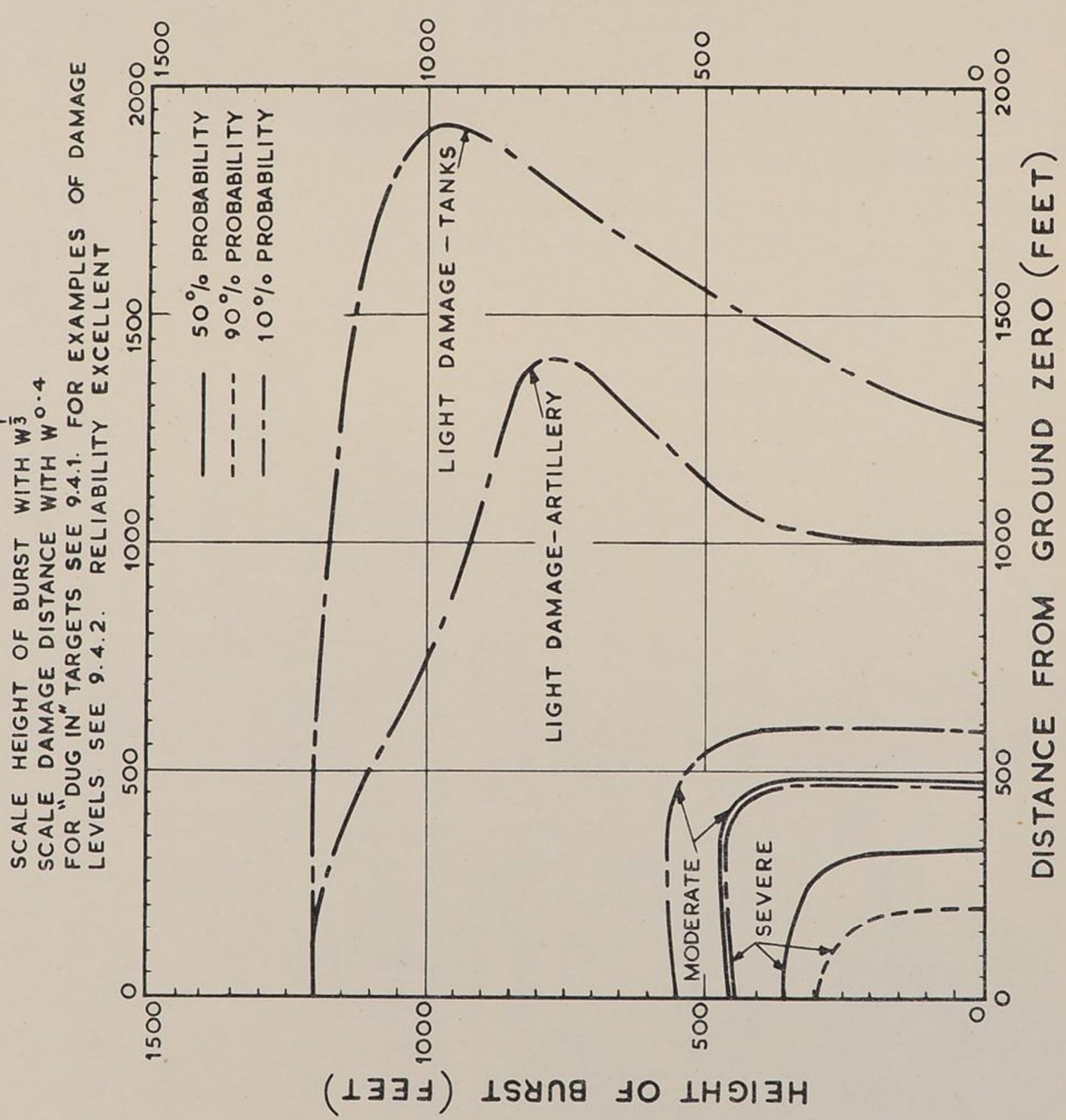


DAMAGE RADIUS REDUCTIONS
FOR UNDERGROUND BURSTS

9.4.2. Tanks, Armoured Vehicles, Artillery, Ordnance Items, etc. - Tanks and artillery are about equally vulnerable except in the light damage category. Table I indicates which set of curves best fits the experimental data for other items of military ordnance. Examples are also given of damage levels for the various items. In all cases scaling to other yields is with $W^{\frac{1}{3}}$ for height of burst, and with $W^{0.4}$ for damage distances. Note that the curves apply to light and heavy vehicles; light, medium and heavy artillery; and light, medium and heavy tanks. The artillery curves include anti-aircraft artillery except for the electronic fire control equipment, which is discussed in Section 9.4.4. Thermal damage to ordnance equipment is generally superficial, such as scorching of paint and tyres. Canvas covers may be ignited from thermal radiation at energies ranging from 15 - 50 calories per sq. c.m. from a 1 KT burst, depending on composition, weight, impregnation, etc.

TABLE I - DAMAGE TO ORDNANCE ITEMS

Item	Damage Curves Most Closely Related	Examples of Severe Moderate and Light Damage
Tanks, all types	Sect.9.4.2. Fig.1	S- extensive turret, main armament and track damage - possible dismemberment. M- overturning, track and turret damage. L- antenna damage.
Artillery	Sect.9.4.2. Fig.1.	S- extensive recoil mechanism, wheel and trail damage, possible dismemberment. M- bent and twisted trails, some recoil mechanism danage, wheels may be torn off. L- sight glass breakage.
Mortars and recoil-less rifles	Sect.9.4.2. Fig.1 (for light damage use artillery curve)	S- Dismemberment. M - Twisted standards and mountings L- Sight breakage
Small arms and machine guns	Sect.9.4.2. Fig.1 (for light damage use artillery curve)	S- Dismemberment. M - Broken stocks, twisted and broken mountings. L - Cracked stocks
Rocket launchers	Sect.9.5.3. Fig.1	S-Torn to pieces. M - Twisted tube. L-Sight damage
LVT's and DUKW's (on land)	Sect.9.5.3. Fig.1	S- Great distortion and possible rupture of hull. M - Hull distortion, track damage. L - Glass breakage



DAMAGE TO TANKS, FIELD ARTILLERY, ETC. 1K.T.

Part III
Chapter 9
Section 9.4.3

Aug. 1957

TABLE I - Overpressures in p.s.i. Required to Detonate Various Mines

Country	Mine	0"-12" Depth of Burial				12"-24" Depth of Burial			
		Percent detonations - 90%		10%		90%		10%	
		Rise Time		Rise Time		Rise Time		Rise Time	
		Fast	Slow	Fast	Slow	Fast	Slow	Fast	Slow
Belgium	PRB ND-49 Heavy Model A/T	20	30	17	25	30	30	25	25
	PRB ND-49 Light Model A/T	20	30	17	25	30	30	25	25
France	Model 1947 A/T	3	3	(*)	(*)	5	5	1.5	1.5
	Model 1948 A/T	15	20	10	15	20	20	15	15
	Model 1948 Plate Charge offset pressure	4	4	1.5	1.5	6	6	2	2
	Model 1951 Undetectable buried spider plate	5	5	2	2	7	7	3	3
	Model 1951 Shaped Charge, steel, offset pressure	4	4	1.5	1.5	6	6	2	2
	Model 1951 Shaped Charge, bakelite offset pressure	10	15	8	12	15	15	12	12
	Model 1948 A/P	4	4	1.5	1.5	6	6	2	2
Germany	TMI-35 A/T	4	4	1.5	1.5	6	6	2	2
	TMI-35 Steel A/T	4	4	1.5	1.5	6	6	2	2
	RMI-42 A/T	17	25	15	20	25	25	20	20
	SCHU A/P	2	2	(*)	(*)	3	3	(*)	(*)
Italy	CS 42/2 A/T	4	4	1.5	1.5	6	6	2	2
	CS 42/3 A/T	4	4	1.5	1.5	6	6	2	2
	CC 48 Shaped Charge A/T	7	7	3	3	9	9	5	5
	P-1 A/T	12	18	9	14	18	18	14	14
	P-2 A/T	12	18	9	14	18	18	14	14
	R A/P	2	2	(*)	(*)	3	3	(*)	(*)
	RM A/P	2	2	(*)	(*)	3	3	(*)	(*)
Turkey	4.4 A/T	7	7	3	3	9	9	5	5
	9.9 A/T	4	4	1.5	1.5	6	6	2	2
U.K.	Mark V (HC) - Buried Spider Plate	10	15	7	11	15	15	11	11
	Mark V (GS) - Buried Spider Plate	10	15	7	11	15	15	11	11
	No.5 Mk. 1 A/P	3	3	(*)	(*)	5	5	1.5	1.5
	No.75 Mk.II	7	7	3	3	9	9	5	5
U.S.A.	M-6 A/T	10	15	7	11	15	15	11	11
	M-7 A/T	35	35	30	30	35	35	30	30
	M-15 A/T	10	15	7	11	15	15	11	11
	M-14 A/P	7	7	3	3	9	9	5	5
	T-18 A/T	10	15	8	12	15	15	12	12
	T-20 A/P	3	3	(*)	(*)	5	5	1.5	1.5
U.S.S.R.	YAM-5 A/T	15	15	11	11	15	15	11	11
	YAM-5K A/T	14	14	10	10	14	14	10	10
	YAM-5M A/T	16	16	12	12	16	16	12	12
	YAM-5U A/T	15	15	11	11	15	15	11	11
	TMS-B A/T	5	5	3	3	8	8	4	4
	TMD-B A/T	15	15	11	11	15	15	11	11
	TM-41 A/T	25	35	20	30	35	35	30	30
	PMP-6 A/P	2	2	(*)	(*)	3	3	(*)	(*)
	PMD-7 A/P	2	2	(*)	(*)	3	3	(*)	(*)

* These mines may detonate in significant percentages at very low pressures (i.e. less than 1.5 p.s.i.

9.4.5. Supply Dumps - Height of burst curves are given in Figure 1 for blast damage to POL stored in 5 or 55 gallon drums (U.S.gallons), ammunition and rations in their standard packaging and other items normally packaged in small containers. The damage indicated refers to the packaging, and is caused by crushing, or by violent displacement and resultant tumbling, of the dump items. For POL, rupture of the packaging results in loss of the contents. However, this may not be the case for other items. Individual rounds of ammunition may be serviceable, even though thrown for great distances. This may also be true for rations. Note that only severe and light damage are indicated. Moderate damage is not considered, because the transition from severe to light damage is so abrupt for this type of target.

Damage Definitions:-

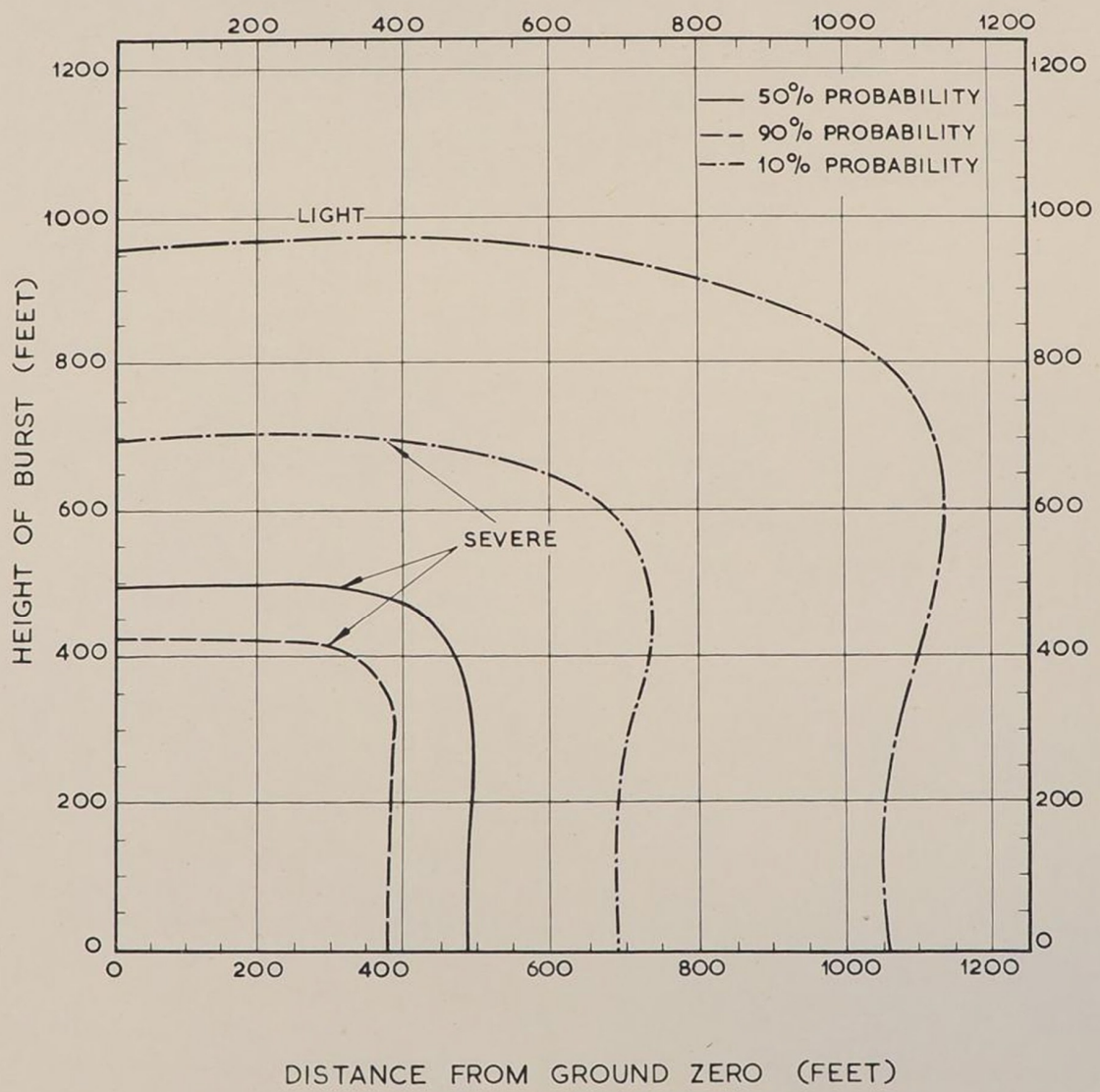
Severe - Rupture of casings, wide scattering, possible destruction of contents.

Light - Scattering of the cases with some cracking and some loss of contents.

Scaling for other yields, heights of burst, and damage distances follows the $W^{\frac{1}{3}}$ rule for height of burst and $W^{0.4}$ for distance, as in the preceeding section.

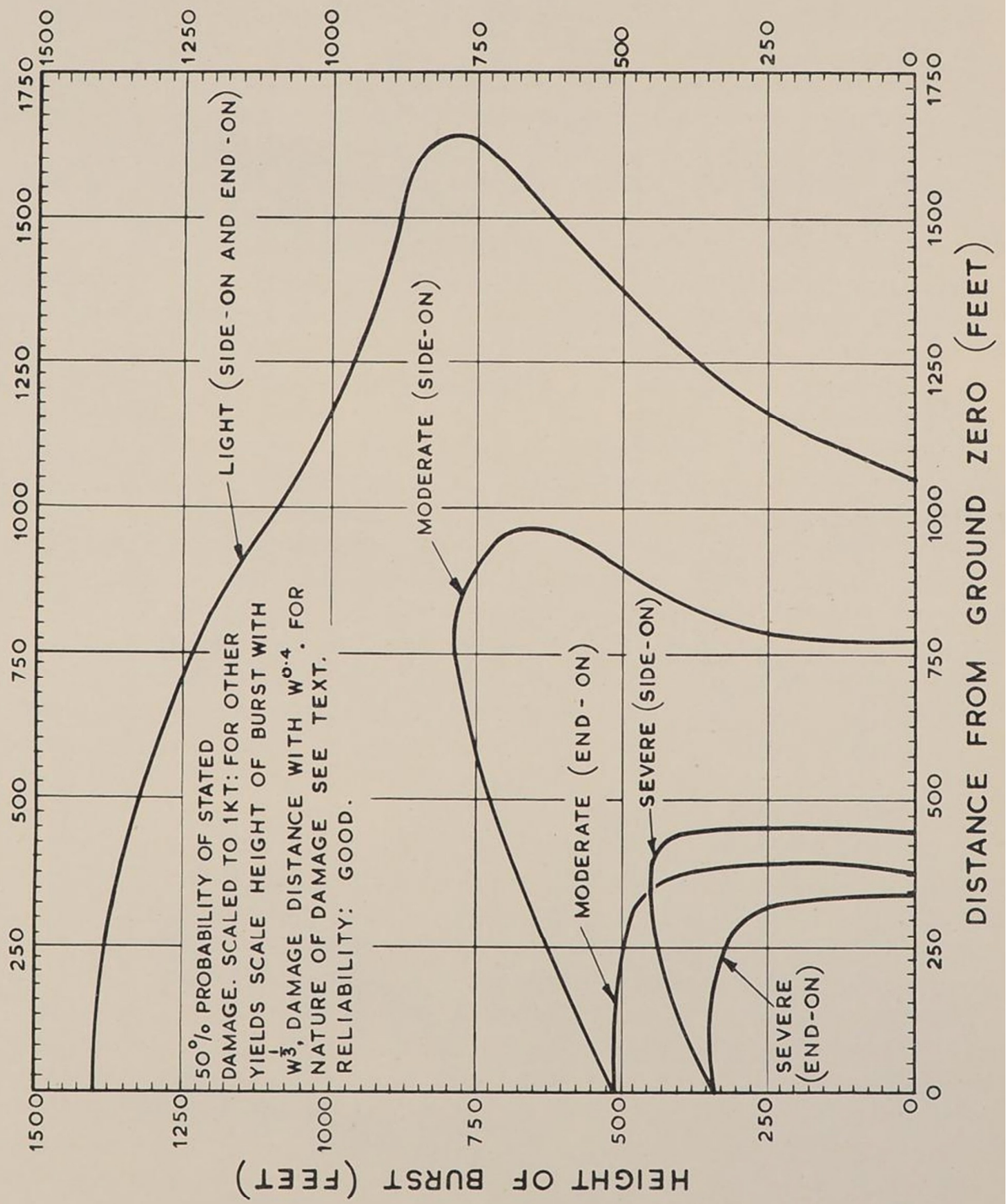
Thermal Damage - Materials in supply dumps packaged in wooden or metal containers are not significantly affected by thermal radiation. However, serious fires may result in supply dumps from the ignition of kindling fuels such as newspaper, dry weeds and grass, and other litter comprised of thin organic materials. These primary ignitions may lead to fires in less combustible materials in the dumps which otherwise would not ignite. POL dumps are highly susceptible to fire under most conditions, owing to the establishment of ignitions in kindling fuels and the subsequent growth of these ignitions into fires, in either accidentally spilled fuels or in fuels spilled from containers ruptured by the blast. Energies required for ignition of various kindling fuels are given in Part 6, Chapter 5, Table 2. In the absence of kindling fuels it is considered unlikely that POL itself will be ignited, whether in open or closed containers or spilled on the ground.

SCALED TO 1KT. FOR OTHER YIELDS SCALE HEIGHT OF BURST WITH $W^{\frac{1}{3}}$, DAMAGE DISTANCE WITH $W^{0.4}$. FOR "DUG IN" TARGETS OR FOR UNDERGROUND BURSTS SEE 9.4.1. RELIABILITY - GOOD.

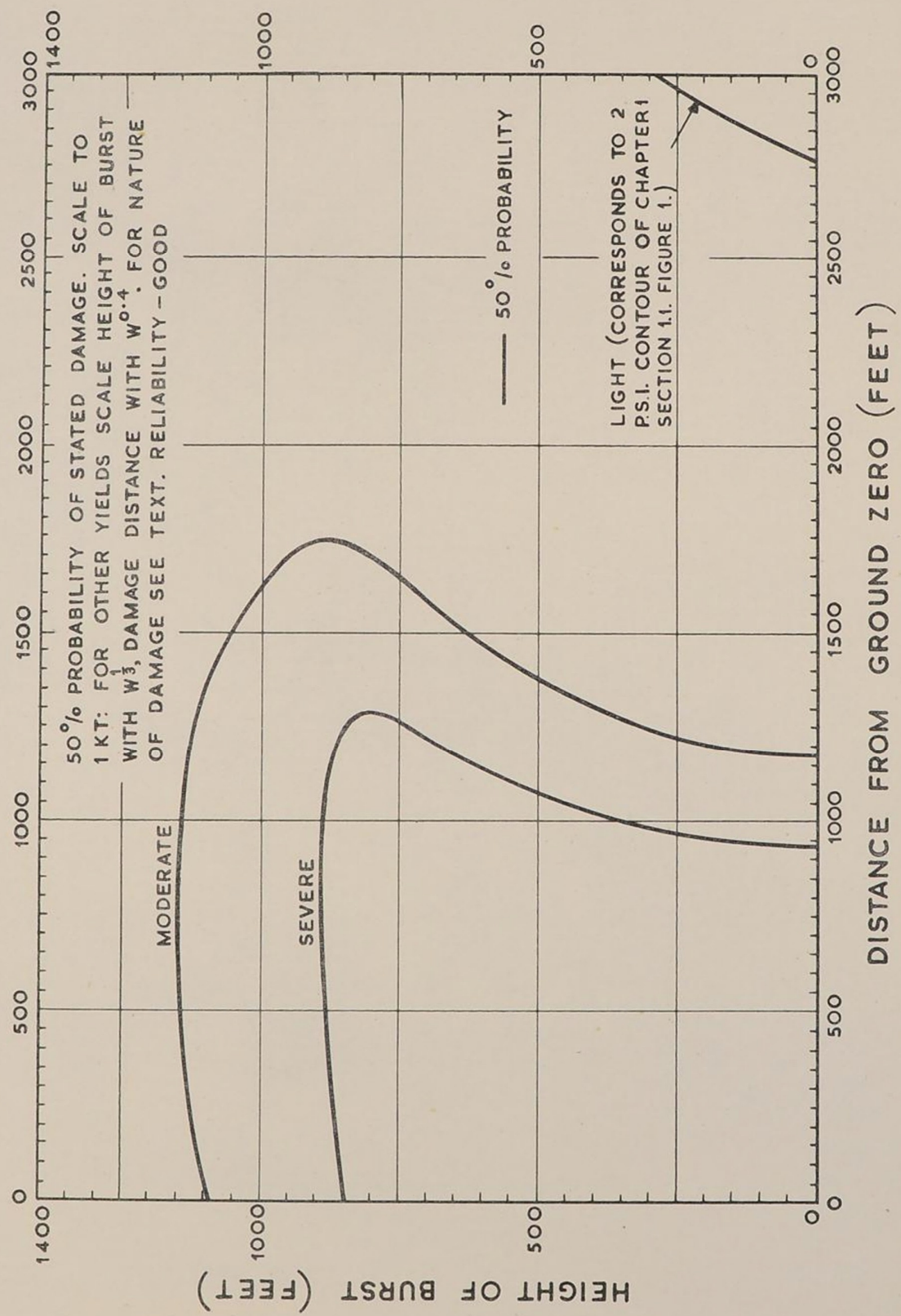


DAMAGE TO SUPPLY DUMPS

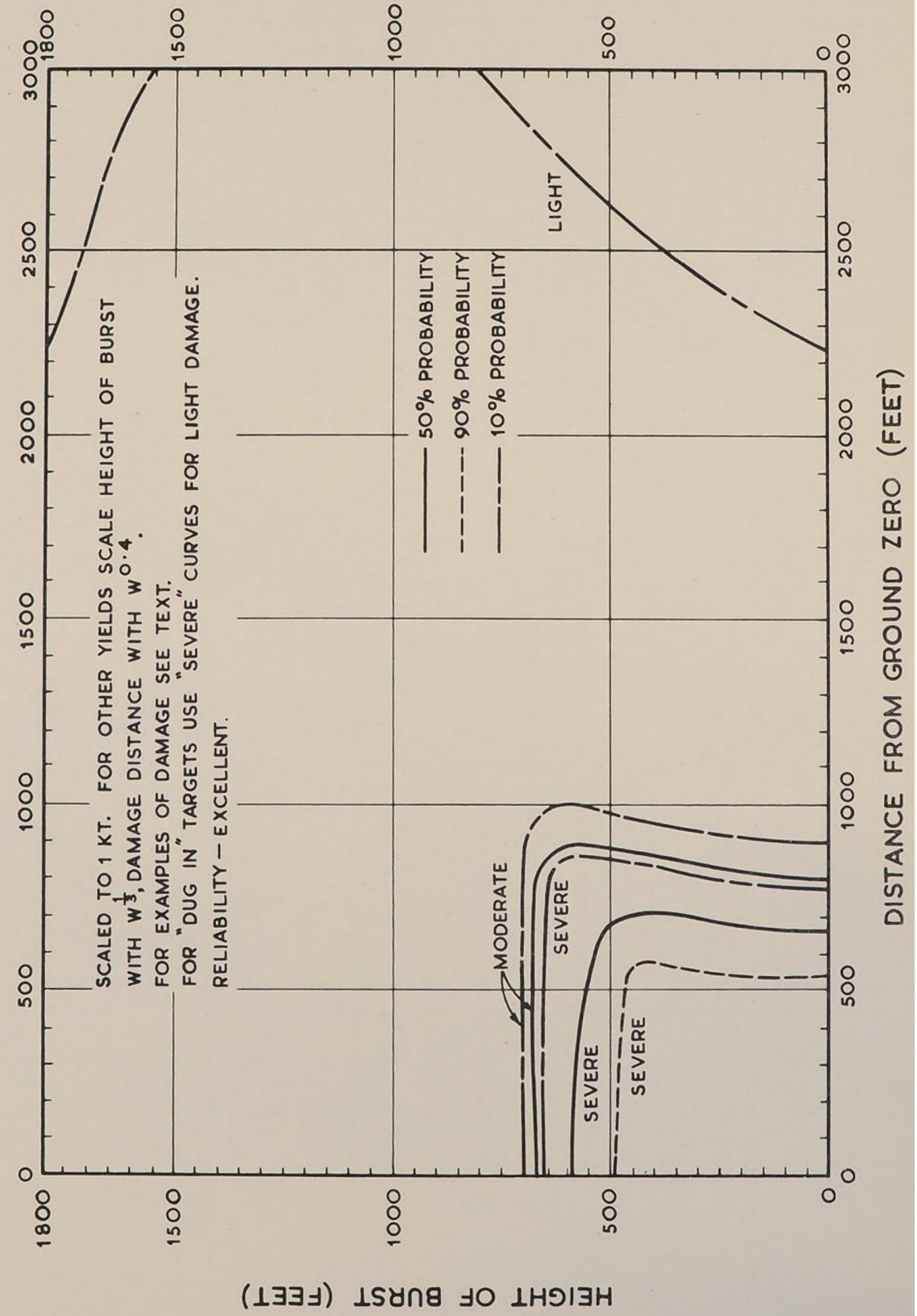
.R.



DAMAGE TO LOCOMOTIVES



DAMAGE TO ROLLING STOCK



DAMAGE TO MOTOR TRANSPORT

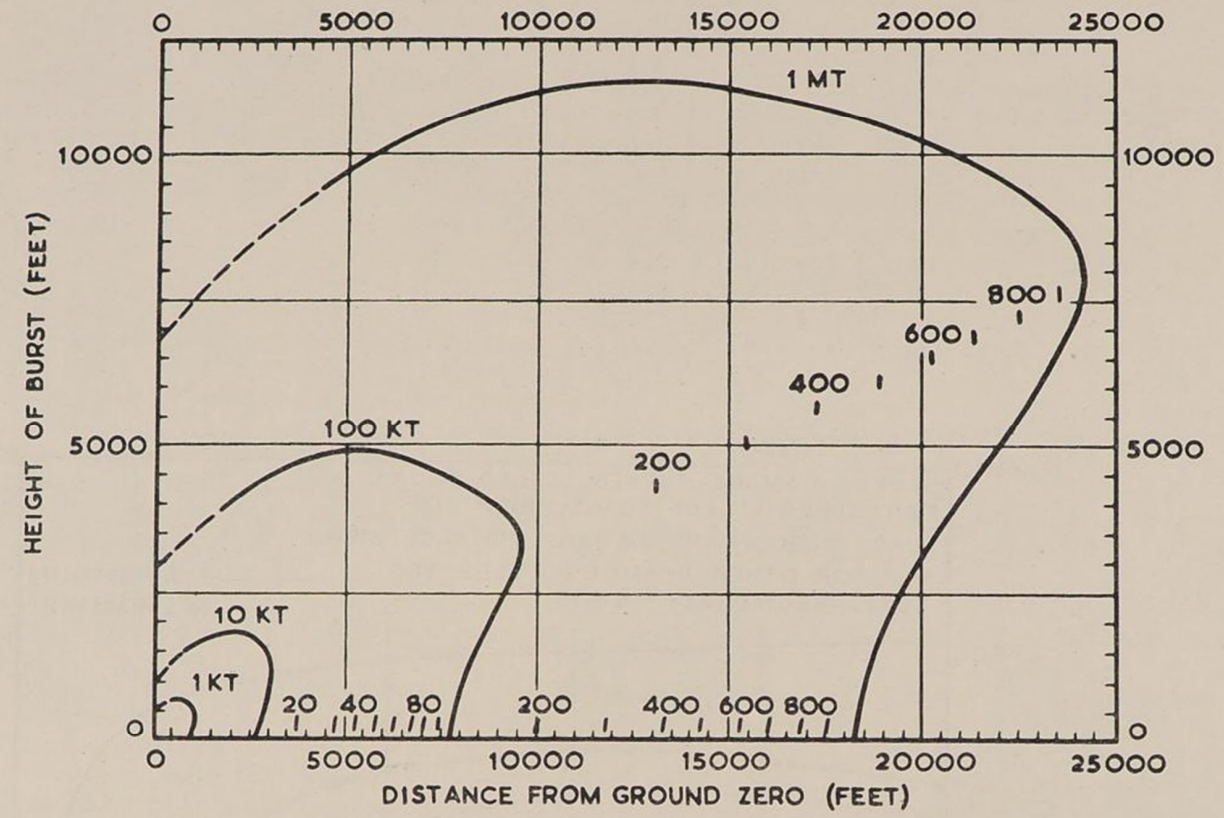


FIG. A. ROUTES RADIAL TO GROUND ZERO

FOR NATURE OF DAMAGE SEE TEXT.
SCALE 1 MT CURVE WITH $W^{\frac{1}{3}}$ FOR GREATER YIELDS.
RELIABILITY – GOOD

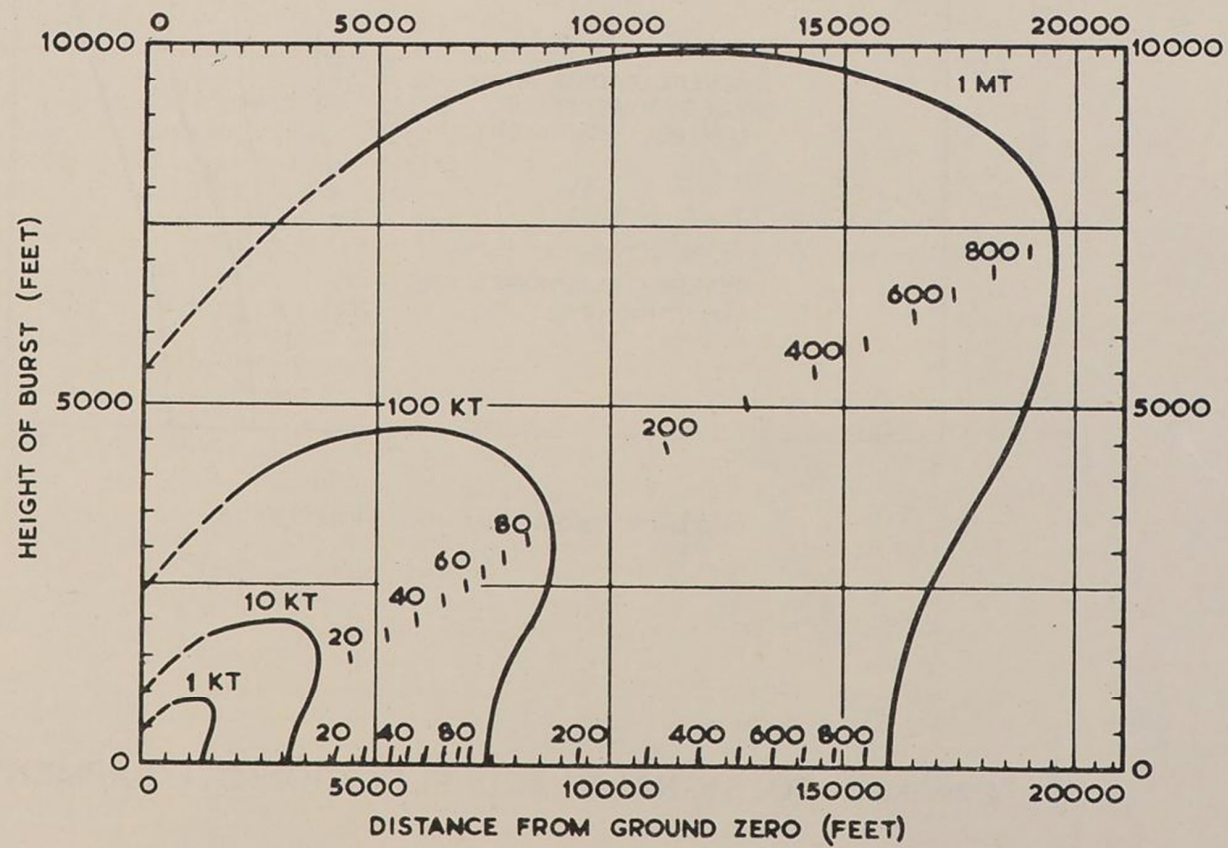


FIG. B. ROUTES TANGENTIAL TO GROUND ZERO

DAMAGE TO POLED TELEPHONE ROUTES

TABLE I - Damage to Structural Types Primarily Affected by Blast Wave Overpressure during the Diffraction Process

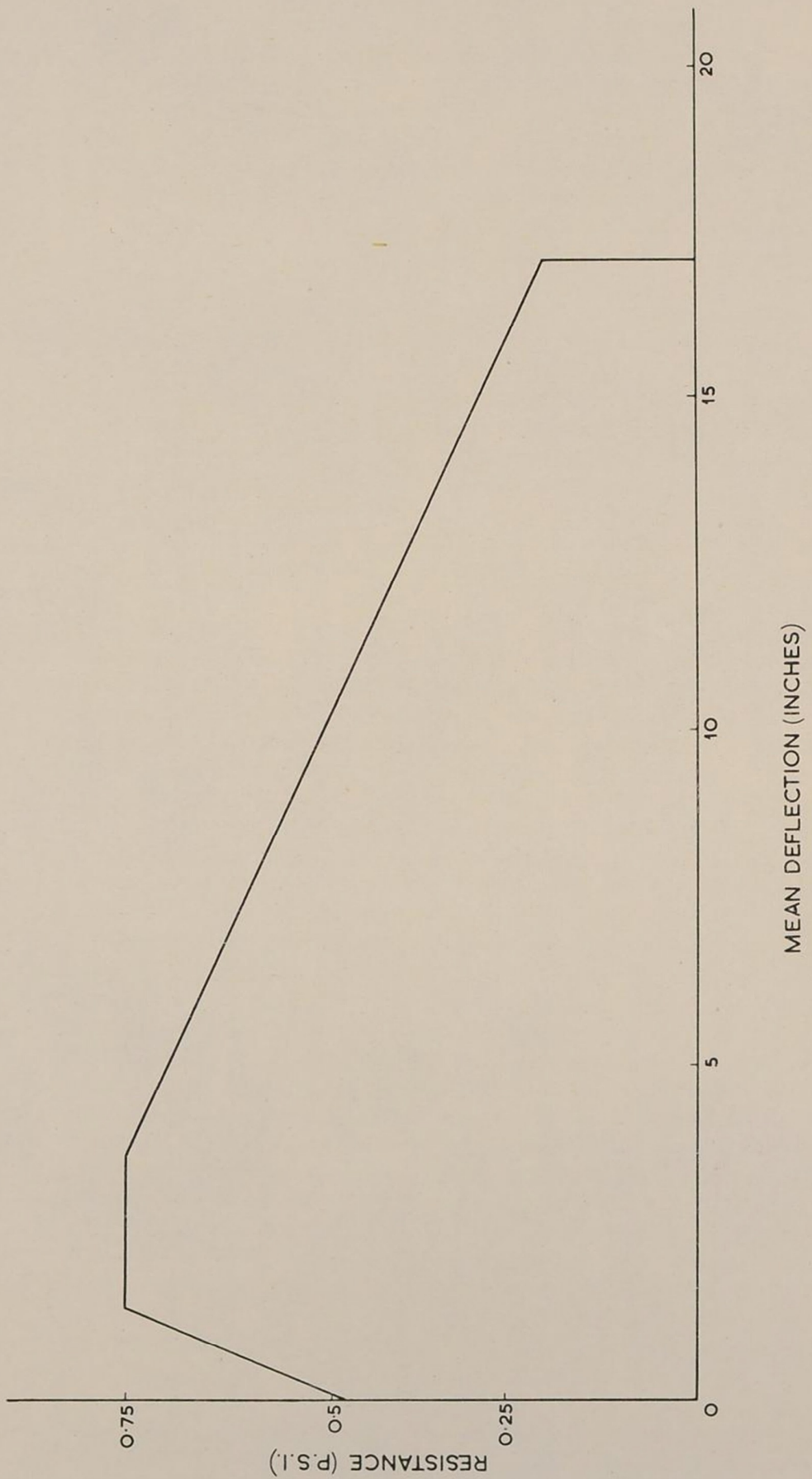
Section	Fig.No.	Description of Structure	Description of Damage		
			Severe	Moderate	Light
9.2.2.	1	Multistory reinforced concrete building with reinforced concrete walls, blast resistant designed, no windows, three storey.	Walls shattered, severe frame distortion, incipient collapse of first floor columns.	Walls cracked building slightly distorted, entranceways damaged, doors blown in or jammed. Some spalling of concrete.	
9.2.2.	2	Multistory reinforced concrete building with concrete walls, small window area, five storey.	Walls shattered, severe frame distortion, incipient collapse of first floor columns.	Exterior walls badly cracked. Interior partitions badly cracked or blown down. Structural frame permanently distorted; spalling of concrete.	Windows and doors blown in. Interior partitions cracked.
9.2.3.	1	Multistory reinforced concrete frame office type building five storey. Light weight low strength walls fail quickly.	Severe frame distortion. Incipient collapse of lower floor columns.	Frame distorted moderately. Interior partitions blown down. Some spalling of concrete.	Windows and doors blown in. Light siding ripped off. Interior partitions cracked.
9.2.4.	1	Multistory steel frame office type building, five storey. Light weight low strength walls fail quickly.	Severe frame distortion. Incipient collapse of lower floor columns.	Frame distorted moderately. Interior partitions blown down.	Windows and doors blown in. Light siding ripped off. Interior partitions cracked.
9.2.5.	1	Heavy steel frame industrial building, single storey, with 50 ton crane capacity. Light weight low strength walls fail quickly.	Severe distortion of frame (½ column height deflection).	Some distortion of frame; cranes, if any, not operable until repairs made.	Windows and doors blown in. Light siding ripped off.
9.2.5.	2	Medium steel frame industrial building, single storey, with 20 ton crane capacity. Light weight low strength walls fail quickly.	Severe distortion of frame (½ column height deflection).	Some distortion of frame; cranes, if any, not operable until repairs made.	Windows and doors blown in. Light siding ripped off.
9.2.5.	3	Light steel frame industrial building, single storey, with up to 5 ton crane capacity. Light weight low strength walls fail quickly.	Severe distortion of frame (½ column height deflection).	Some distortion of frame; cranes, if any, not operable until repairs made.	Windows and doors blown in. Light siding ripped off.
9.2.6.	1	Multistory wall bearing building, monumental type four storey.	Bearing walls collapse resulting in collapse of structure supported by these walls. Some bearing walls may be shielded enough by intervening walls so part of structure may receive only moderate damage.	Exterior walls facing blast badly cracked, interior partitions badly cracked, although toward far end of building damage may be reduced.	Windows and doors blown in. Interior partitions cracked.
9.2.6.	2	Multistory wall bearing building, brick apartment house type, up to three storey.	Bearing walls collapse resulting in total collapse of structure.	Exterior walls badly cracked, interior partitions badly cracked or blown down.	Windows and doors blown in. Interior partitions cracked.
9.2.7.	1	Wooden frame building, house type, one or two stories.	Frame shattered so that structure is for the most part collapsed.	Wall framing cracked. Roof badly damaged. Interior partitions blown down.	Windows and doors blown in. Interior partitions cracked.
9.2.8.	2	Highway and railroad truss bridges, spans of 150ft. to 250ft. (See figure title for effects of orientation.)	Total failure of lateral bracing, collapse of bridge.	Some failure of lateral bracing such that bridge capacity is reduced about 50%	Capacity of bridge unchanged. Slight distortion of some bridge components (use q = 0.6 psi curve scaled to weapon yield.
9.2.8.	3	Highway and railwoad truss bridges, spans 250ft. to 550ft. (See figure title for effects of orientation.)	Total failure of lateral bracing, collapse of bridge.	Some failure of lateral bracing such that bridge capacity is reduced about 50%.	Capacity of bridge unchanged. Slight distortion of some bridge components. (Use q = 0.6 psi curve scaled to weapon yield.)
9.2.8.	4	Floating bridges, U.S. Army Standard M-2 and M-4, random orientation.	All anchorages torn loose, connections between treadways or walk and floats twisted and torn loose, many floats sunk.	Many bridle lines broken, bridge shifted on abutments, some connections between treadways or walk and floats torn loose.	Some bridle lines broken, bridge capacity unimpaired.
9.2.9.	1	Oil tanks, 30ft. in height, 50ft. in diameter. (Tanks considered full; more vulnerable if empty.	Large distortions of sides, seams split, so that most of contents are lost.	Roof collapsed, sides above liquid buckled, some distortion below liquid level.	Roof badly damaged.

6.2 Methods of Solution

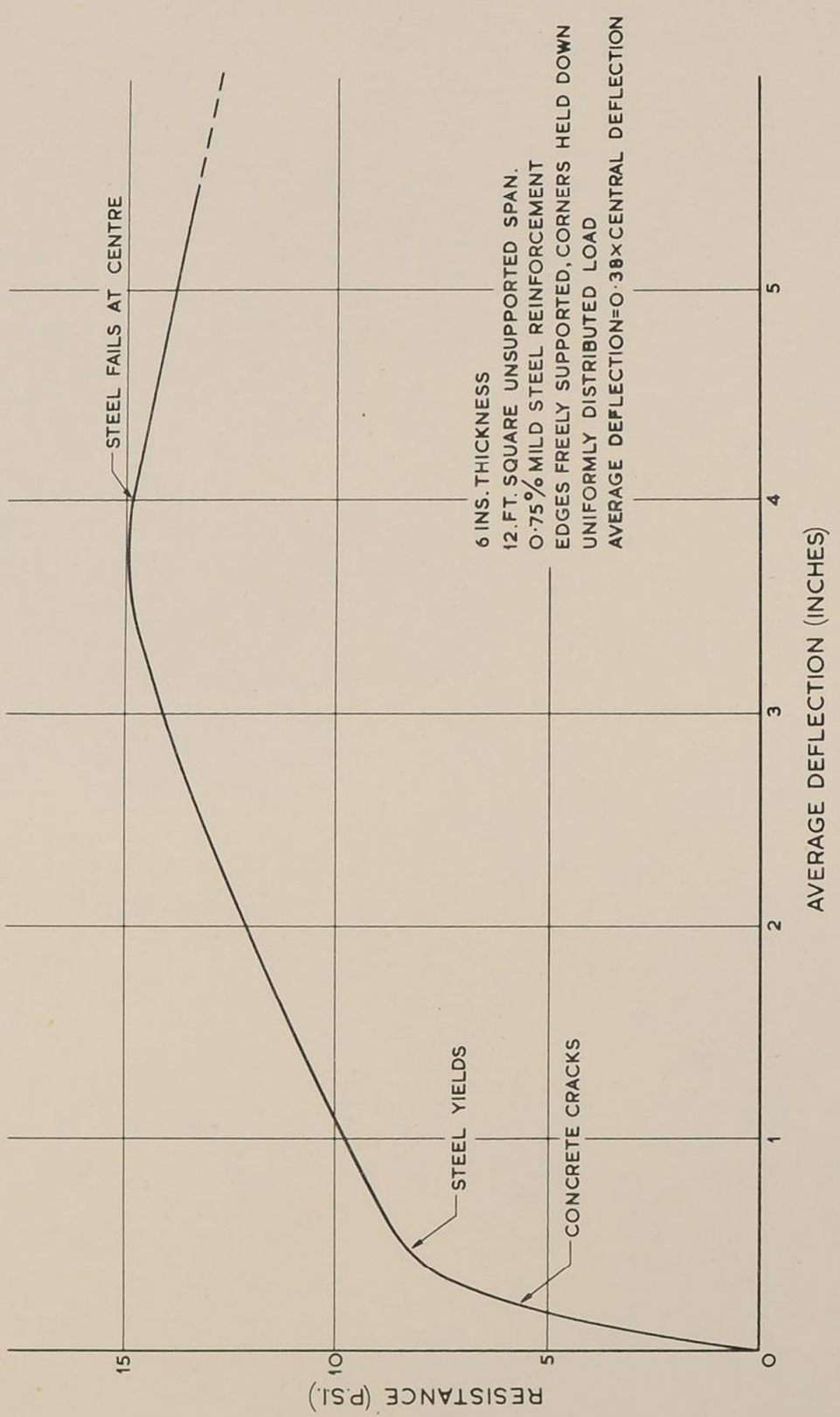
The basic equation of motion to be solved is

$$M\ddot{x} + b\dot{x} + F(x) = P(t) \qquad (6.3)$$

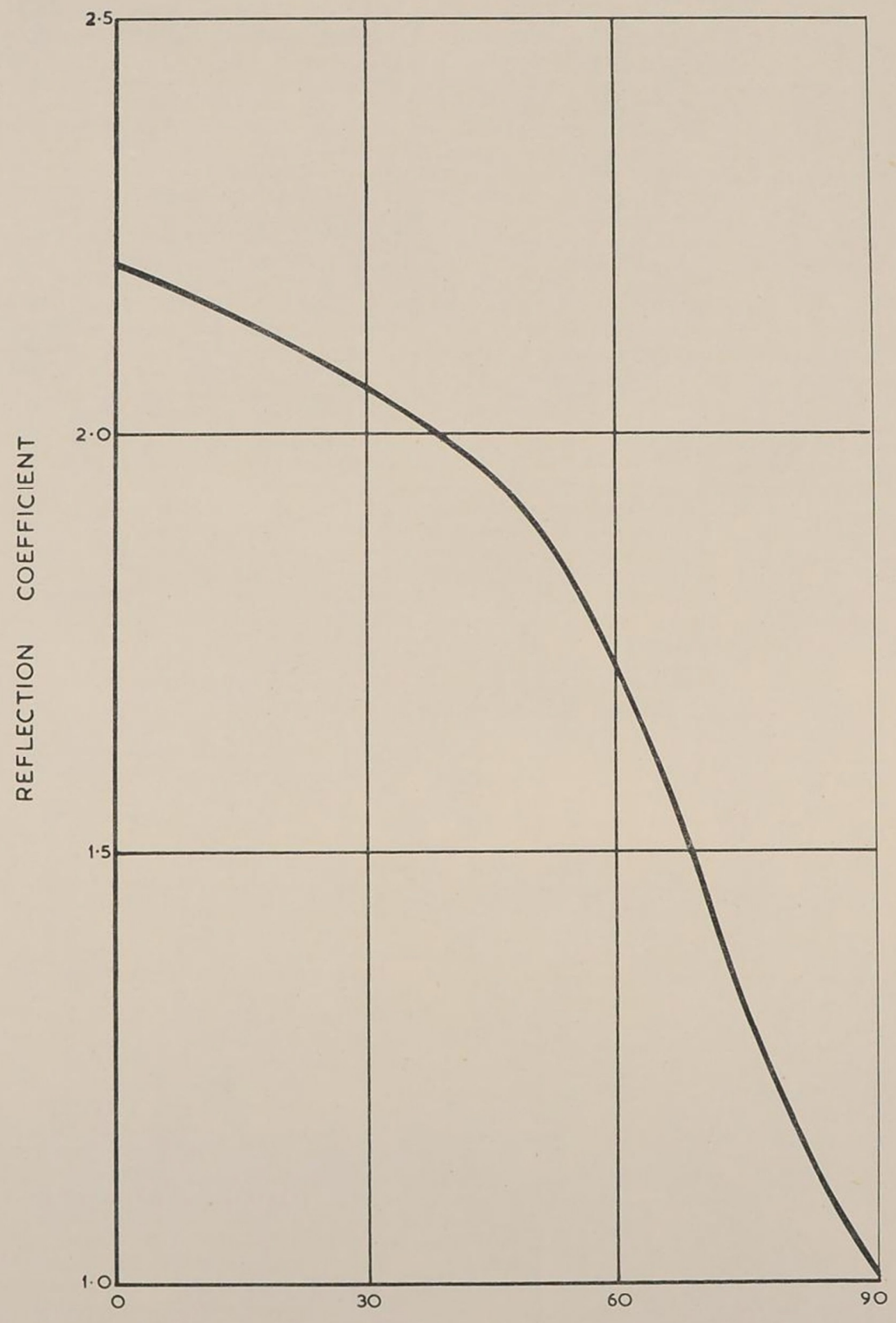
where $F(x)$ and $P(t)$ are either experimentally or empirically determined functions. We can obtain an approximate step-by-step solution to (6.3) either by direct numerical integration or by a semi-graphical (phase-plane) method, or we can approximate $F(x)$ and $P(t)$ by simple analytical functions and obtain an exact solution of the resulting equation. The last method involves the most work, but once the solution has been obtained in general terms it may be expressed graphically and applied to a large class of problems. The three methods of solution will be described in turn.



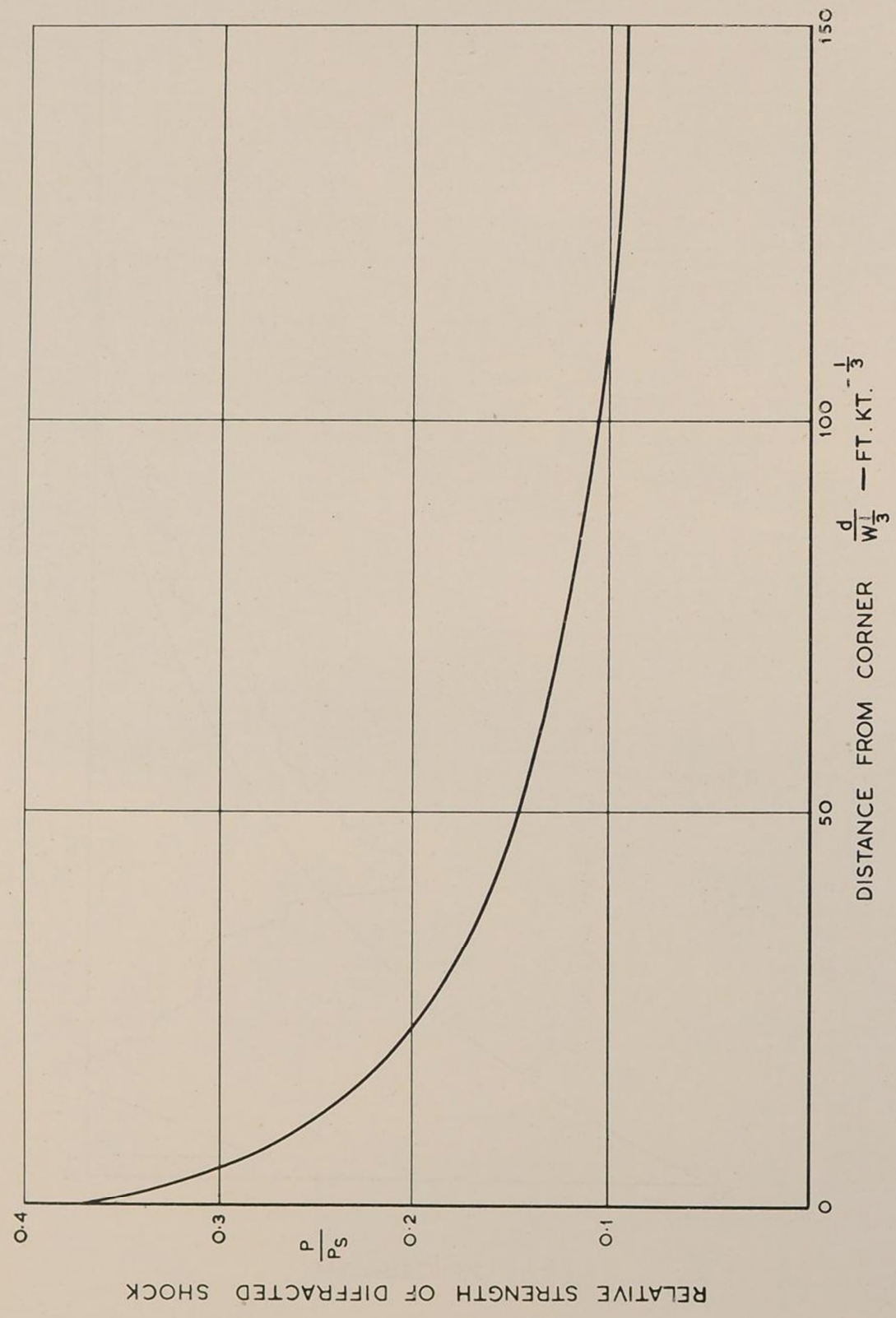
RESISTANCE/DEFLECTION CURVE FOR HOUSE WITH LOAD-BEARING WALLS



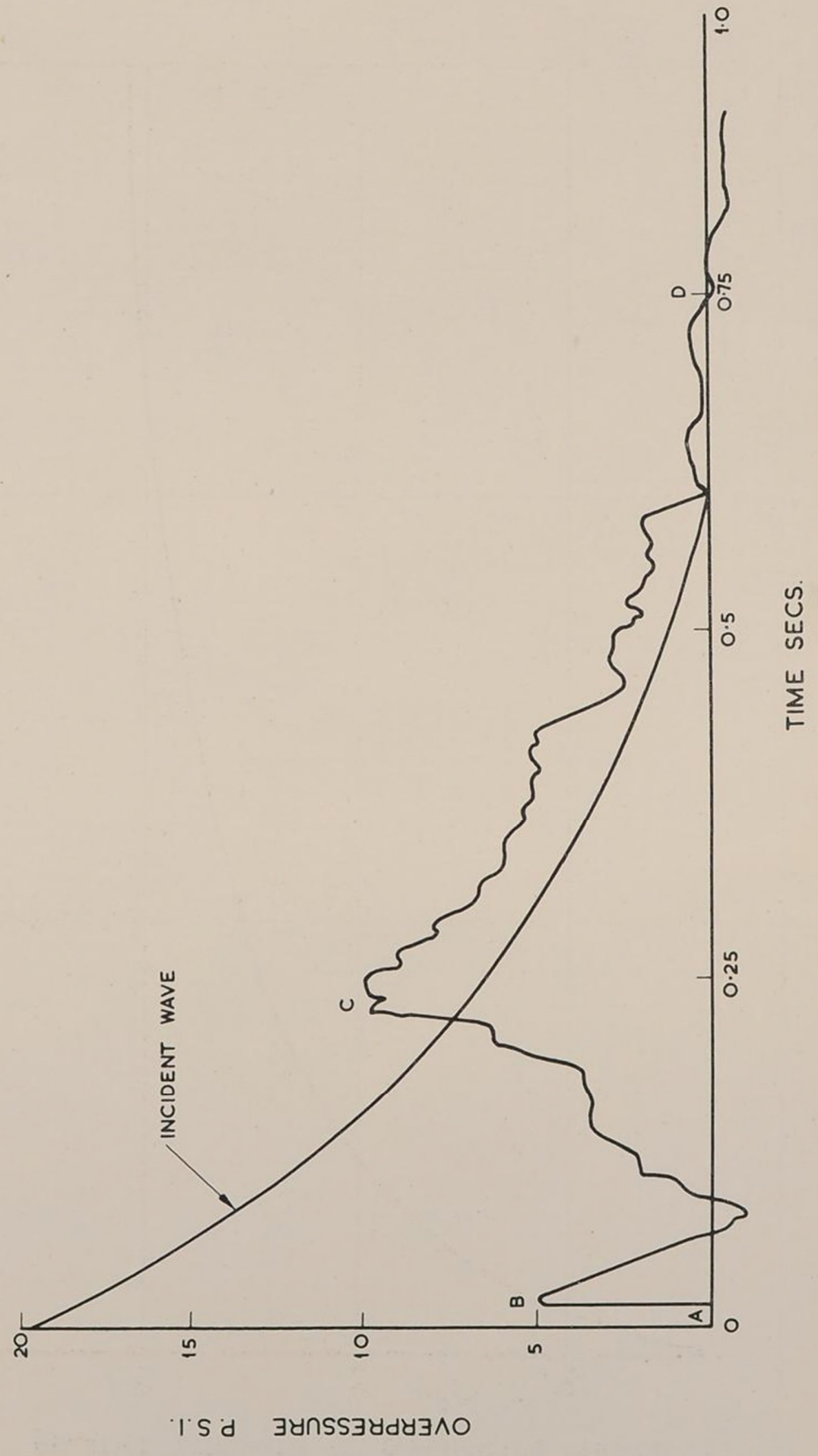
STATIC LOAD/DEFLECTION CURVE FOR REINFORCED CONCRETE PANEL



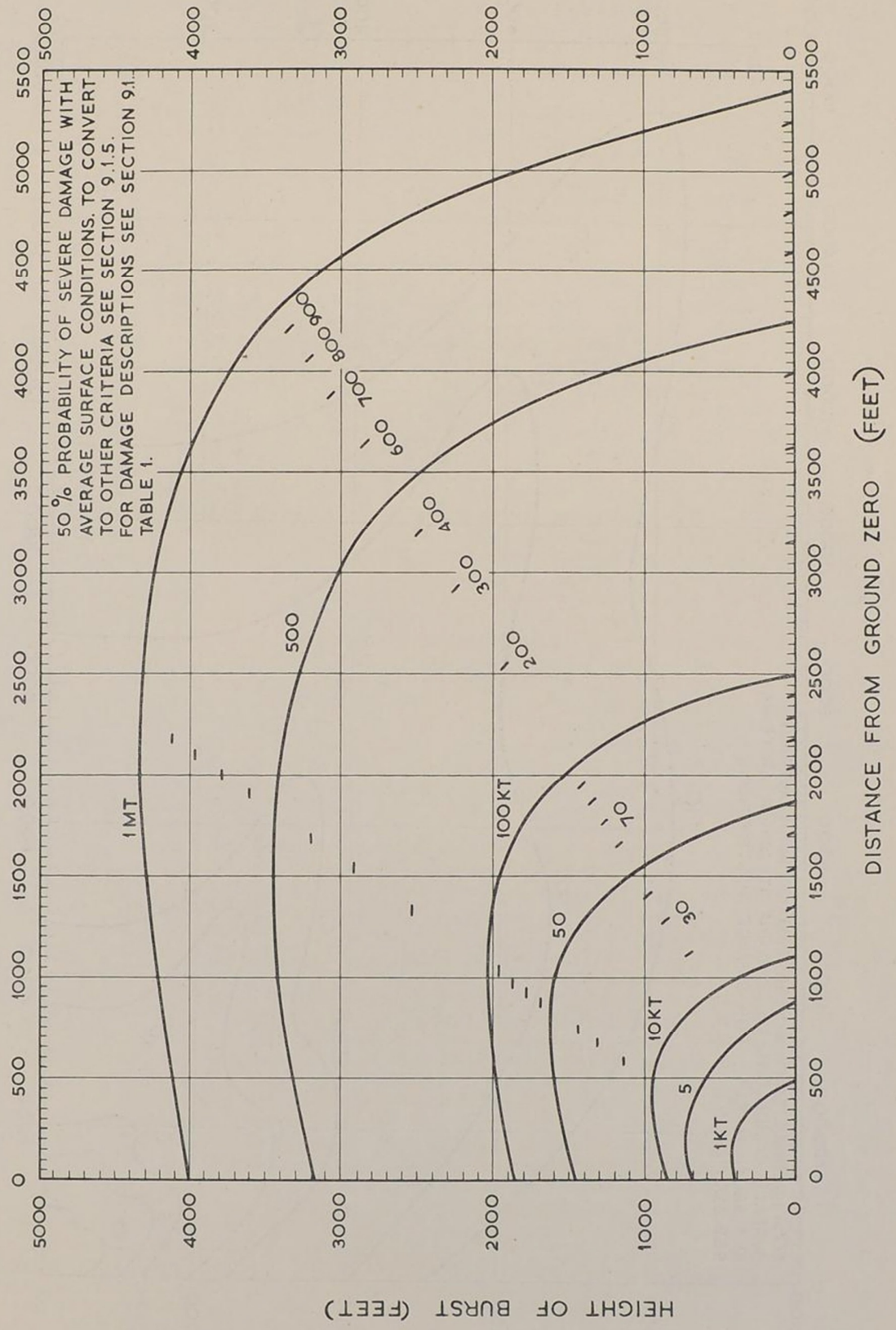
REFLECTION COEFFICIENT AT VARIOUS ANGLES FOR A SHOCK OVERPRESSURE OF 3·5 P.S.I.



ATTENUATION OF A DIFFRACTED SHOCK



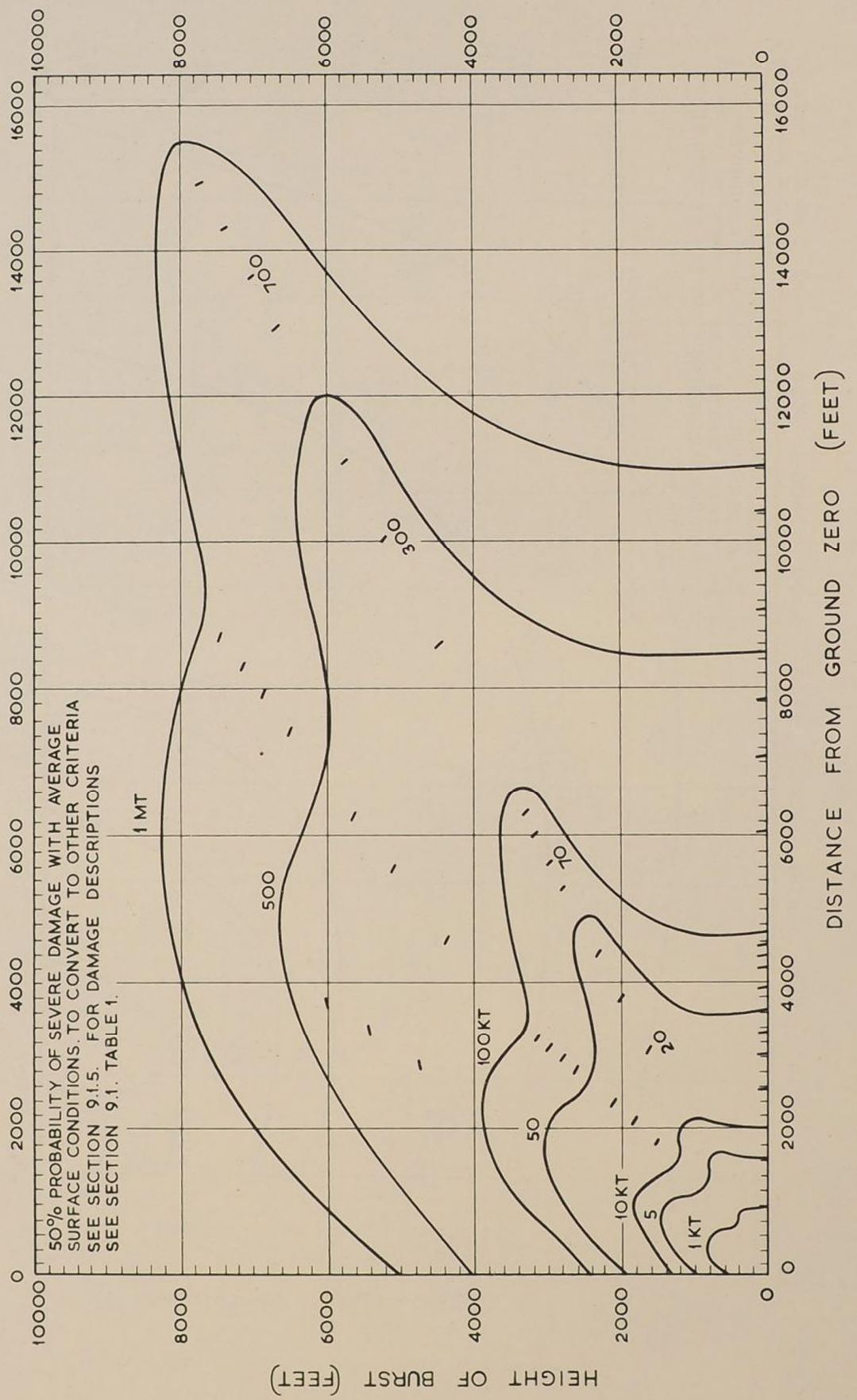
LOADING ON THE REAR WALL OF A BUILDING



DAMAGE TO REINFORCED CONCRETE 3-STOREY CITADELS WITH REINFORCED CONCRETE WALLS.

PART III
CHAPTER 9
SECTION 9.2.2.
FIGURE 2

SECRET ATOMIC



DAMAGE TO REINFORCED CONCRETE 5-STOREY BUILDINGS WITH UNREINFORCED CONCRETE WALLS.

SECRET ATOMIC

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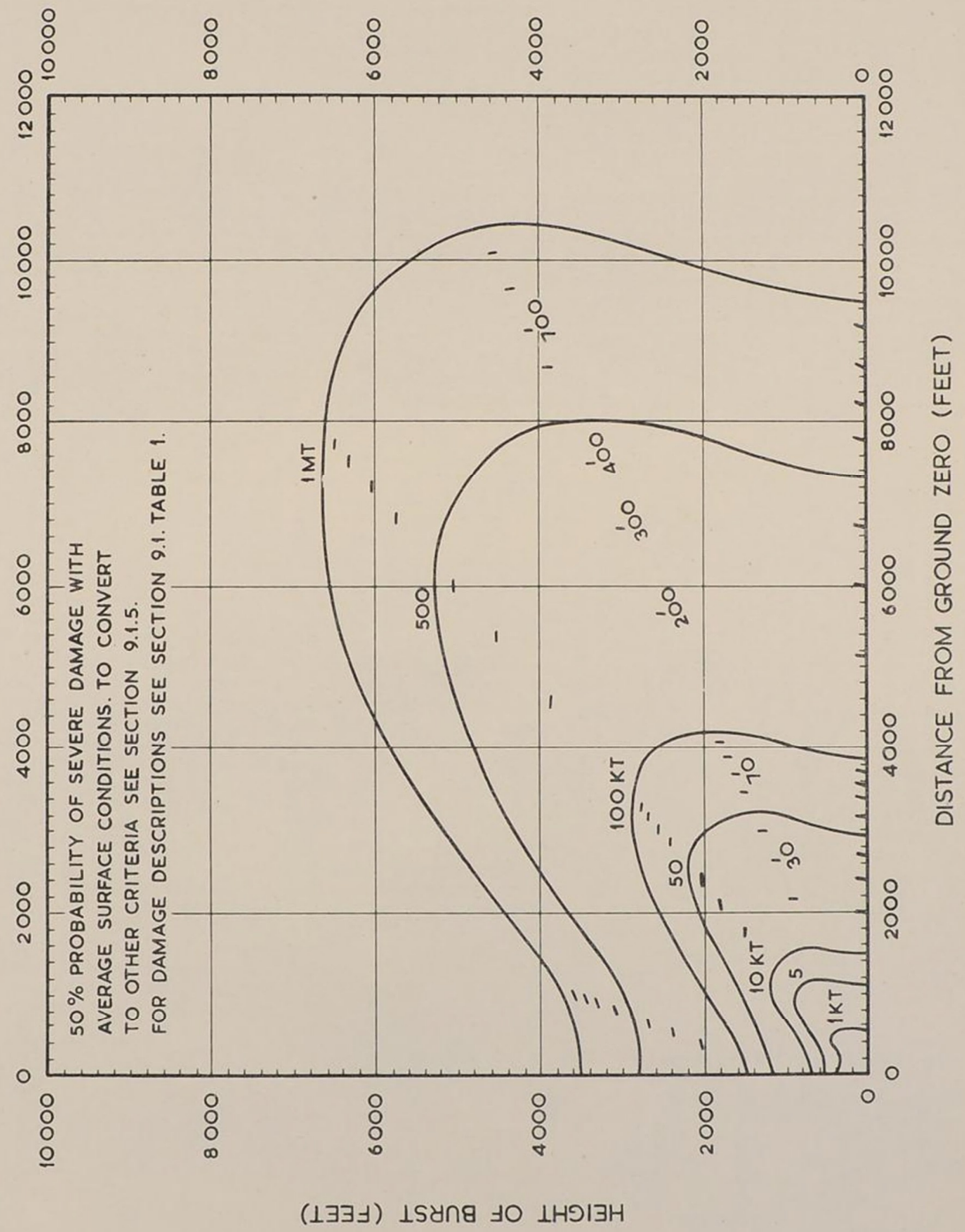
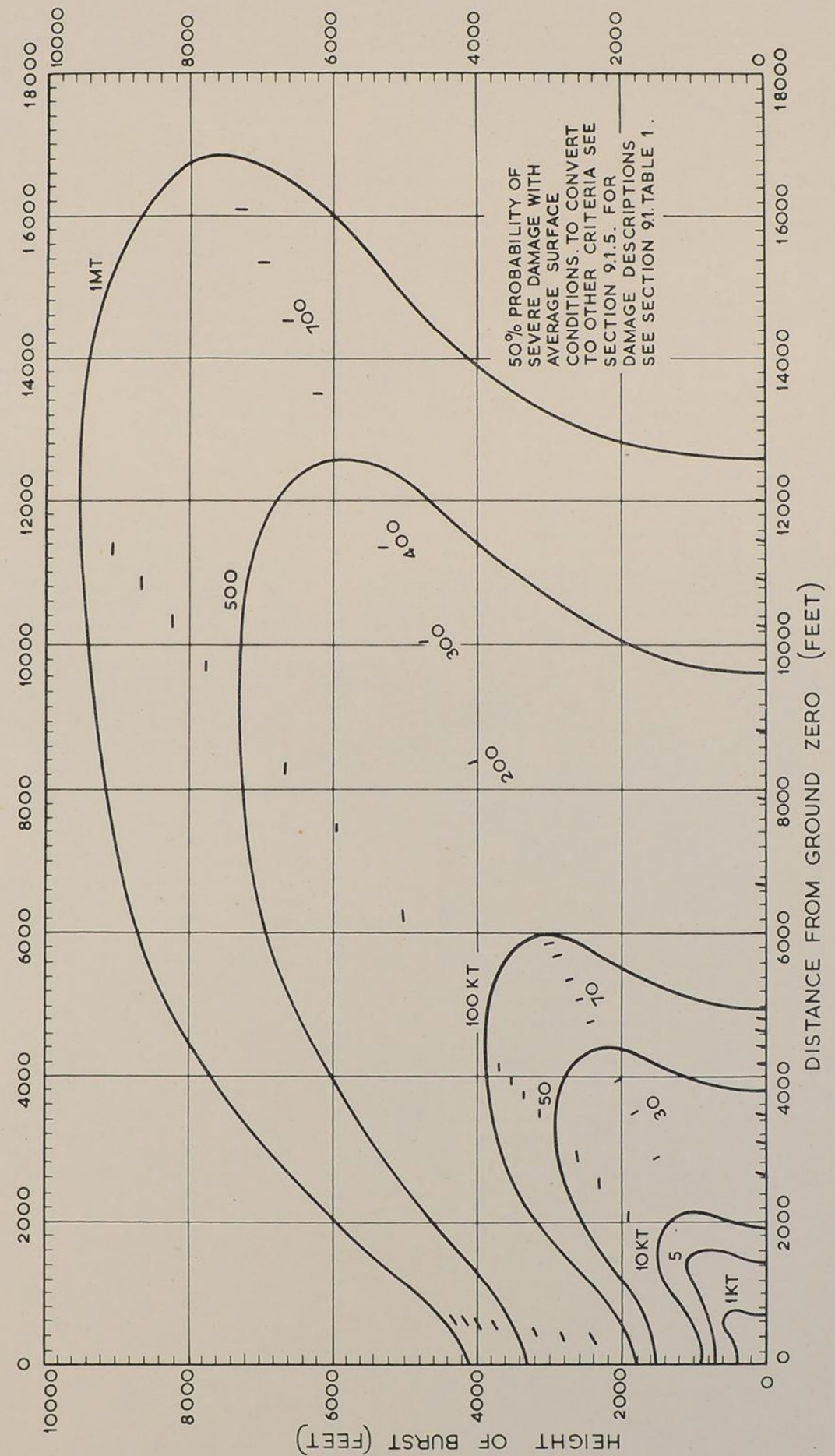
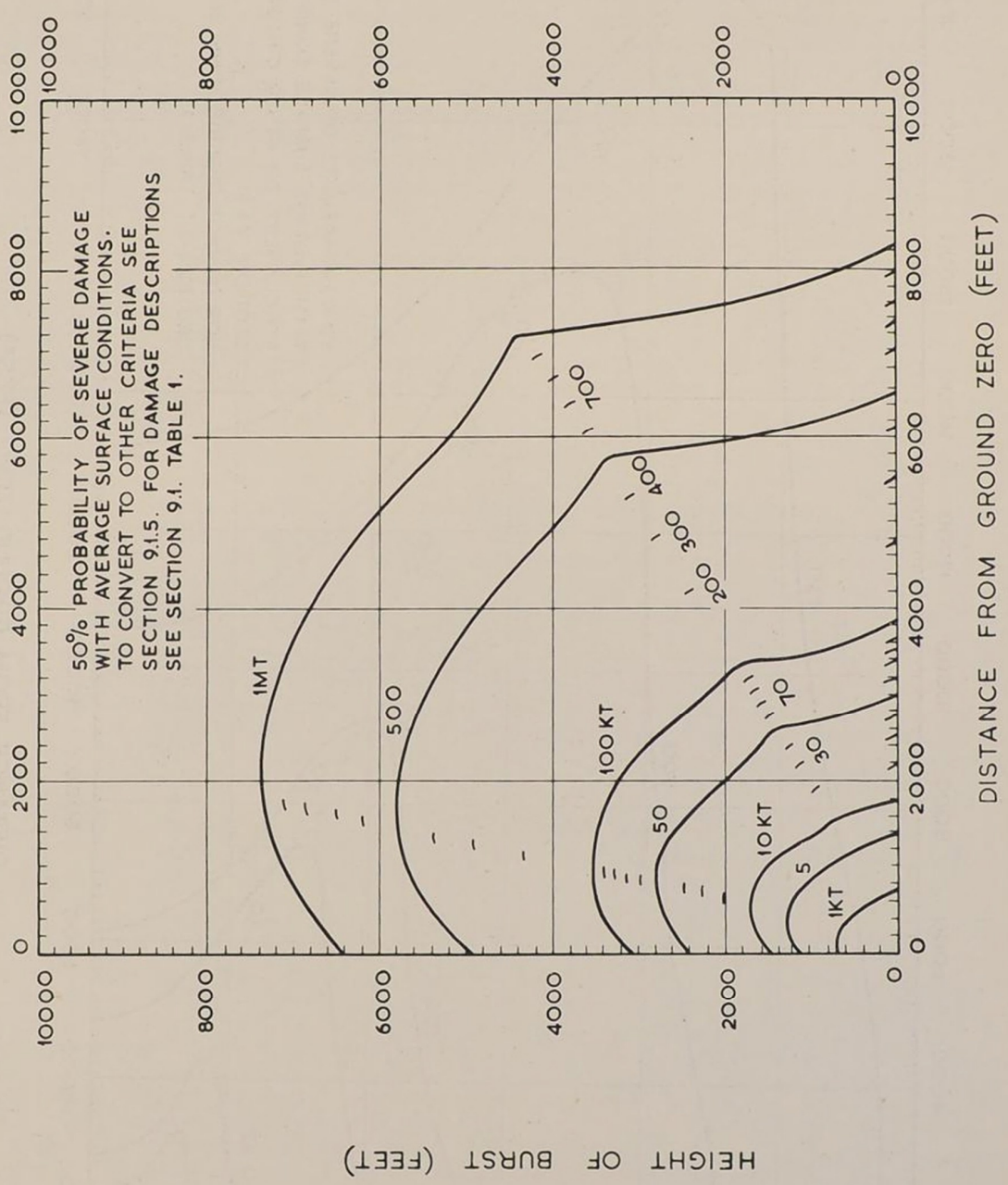


DAMAGE TO 5-STOREY REINFORCED CONCRETE FRAME OFFICE-TYPE BUILDINGS WITH LIGHT WALLS.

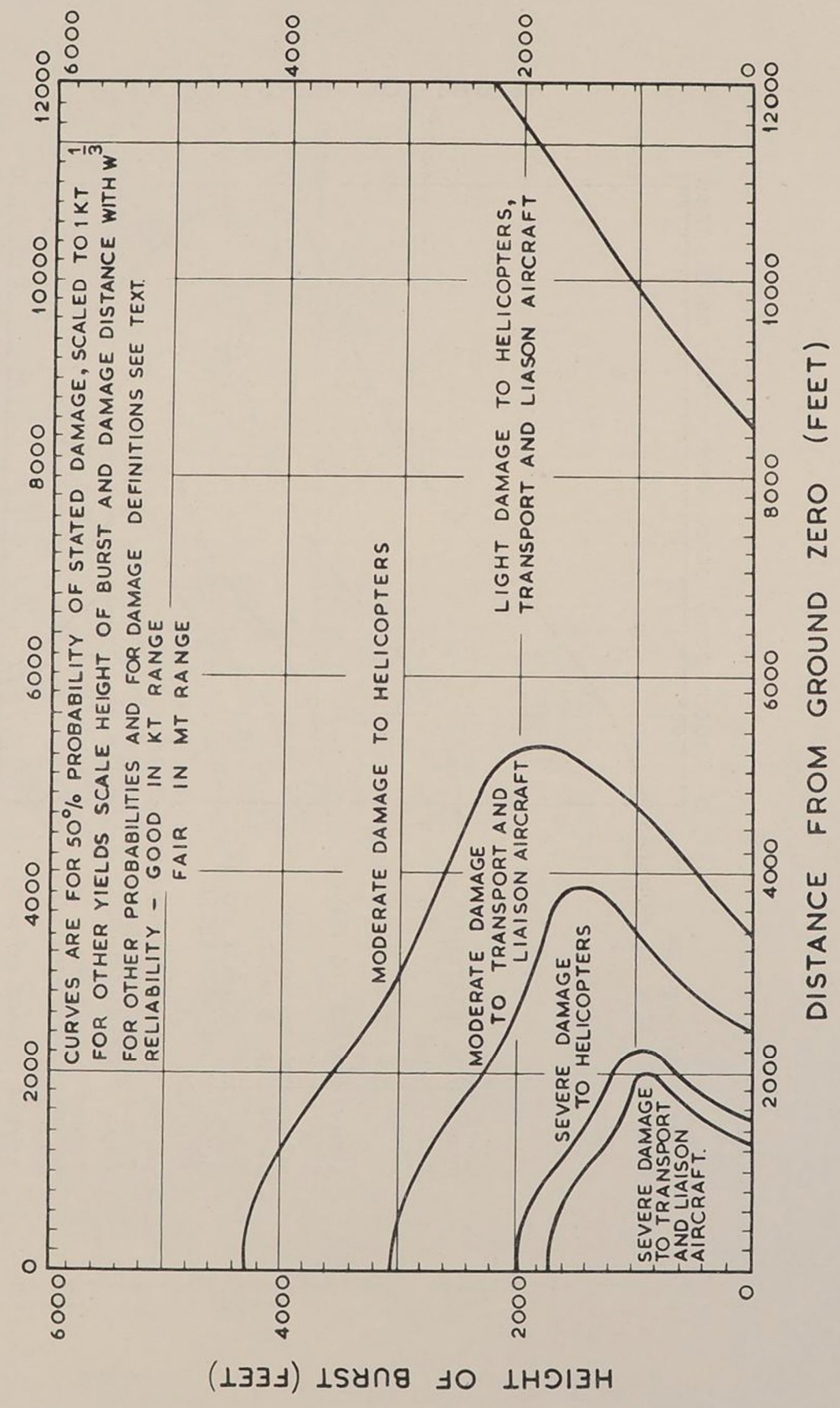
PART III
CHAPTER 9
SECTION 9.2.4.
FIGURE 1



DAMAGE TO 5-STOREY STEEL FRAME
OFFICE-TYPE BUILDINGS WITH LIGHT WALLS



DAMAGE TO MONUMENTAL TYPE 4-STOREY BUILDINGS WITH LOAD-BEARING WALLS



DAMAGE TO AIRCRAFT ON THE GROUND.
COMMUNICATIONS & TRANSPORT TYPES, RANDOM ORIENTATION

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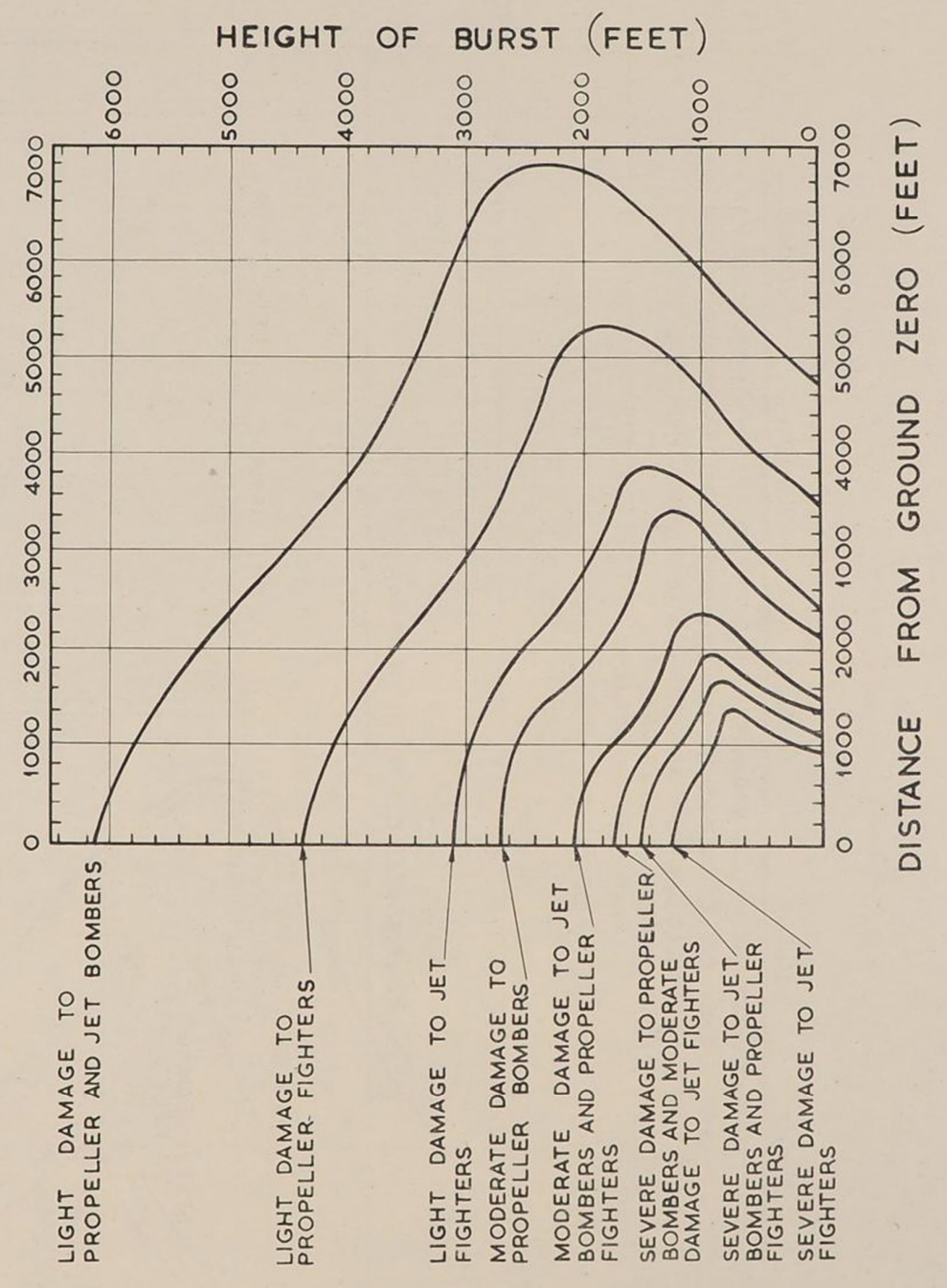
SEPT 1957

PART III
CHAPTER 9.
SECTION 9.6.2.
FIGURE 2.



DAMAGE TO AIRCRAFT ON THE GROUND.
COMBAT TYPES, RANDOM ORIENTATION

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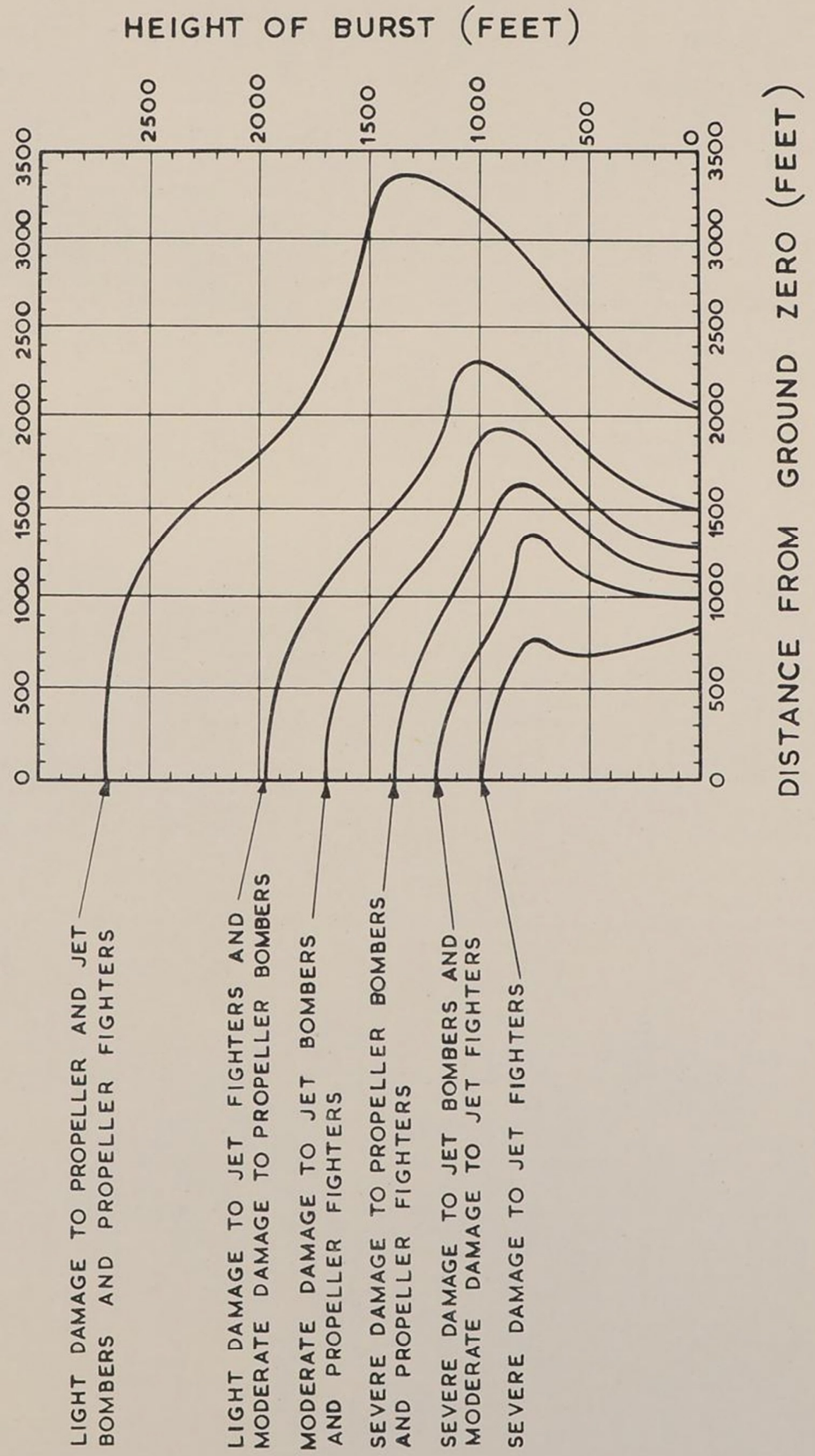
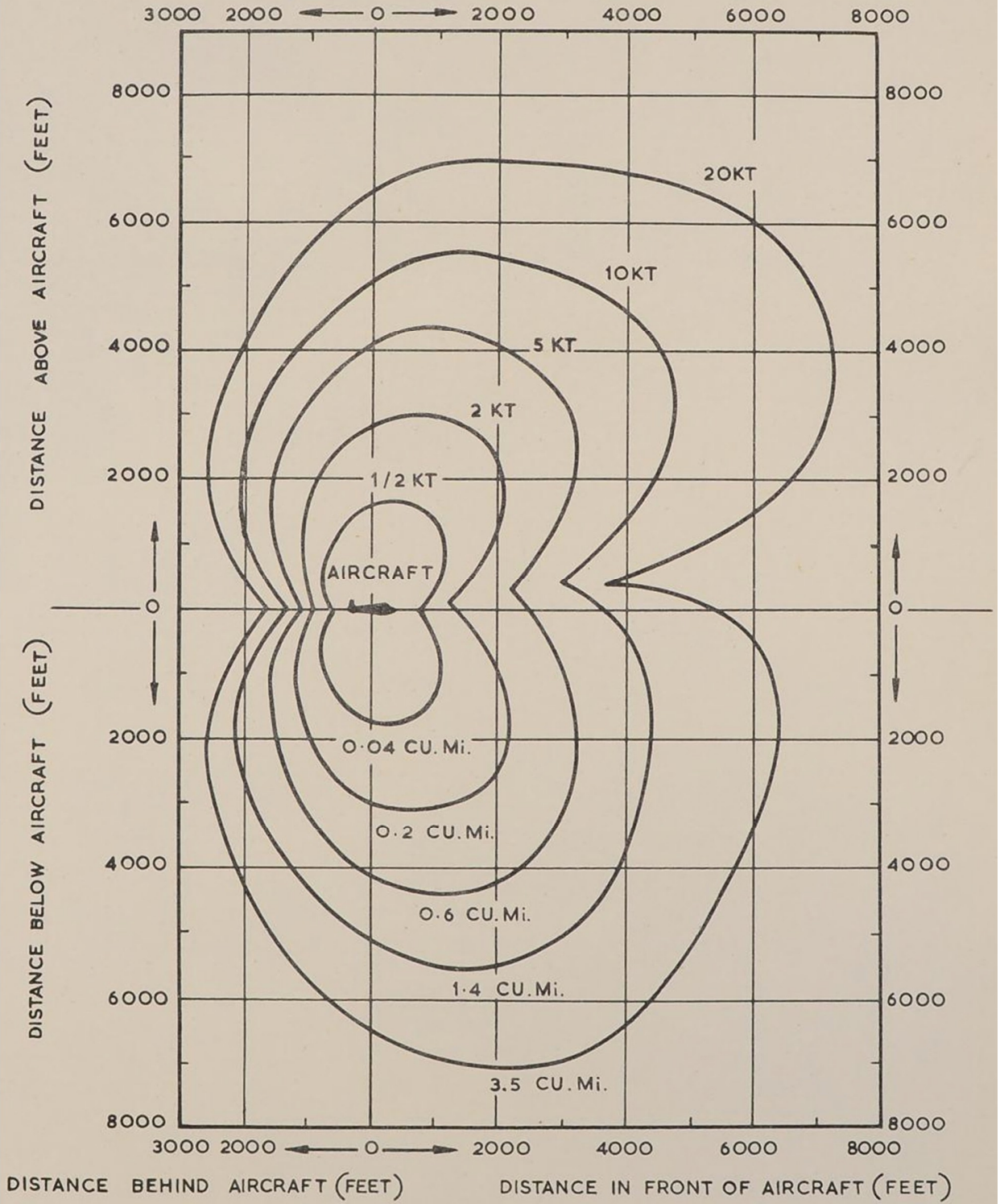


DAMAGE TO AIRCRAFT ON THE GROUND.
COMBAT TYPES, NOSE-ON ORIENTATION

THESE CURVES ARE PRESENTED PRIMARILY TO ILLUSTRATE GENERAL SHAPES AND MAGNITUDES OF LETHAL GUST ENVELOPES FOR BOMBER TYPE AIRCRAFT. IT IS NOT INTENDED THAT NUMERICAL DATA DERIVED BE APPLIED DIRECTLY TO ANY SPECIFIC AIRCRAFT MODELS. CUBE ROOT SCALING OF THE 20 KT CURVE WILL INDICATE APPROXIMATE ENVELOPES FOR LARGER YIELDS.



DAMAGE TO AIRCRAFT IN FLIGHT.
TYPICAL LETHAL GUST ENVELOPES

9.7. SHIPS AND MARITIME OBJECTS

9.7.1. Surface Vessels *

In addition to damage by water shock and surface waves, as described in Part V, mechanical damage to surface ships may be caused by air blast. Thermal damage to shipping is not considered an important factor in that it does not, of itself, cause sinking or immobilisation. As the depth of a burst is decreased, a transition from water shock to air blast as the controlling damage parameter occurs. Air blast is also the controlling damage parameter in the case of air bursts. Peak pressure is considered a satisfactory parameter for estimating damage to ships from air blast. A peak overpressure of 5 p.s.i. causes light damage to most types of surface ships. The peak overpressures required for severe damage vary from 25 p.s.i. for destroyers, to 45 p.s.i. for battleships; Figures 1 and 2 give damage ranges for a 1 KT burst. For heights of burst less than 600 ft.$_1$ and depths of burst less than 800 ft., heights and distances scale with $W^{\frac{1}{3}}$ for other yields, although owing to the limited amount of data available only fair reliability can be assumed. The predictions also become less reliable at the shallower depths of burst. A tabulation of peak overpressure required to cause ship damage is given in Table I for use with burst heights greater than those shown in Figures 1 and 2. For these burst heights distances to which these overpressures extend are obtained from the usual height of burst/overpressure curves.

TABLE I - Surface Ship Peak Air Overpressure Damage Criteria

	Peak Air Overpressure (p.s.i.)		
	Severe	Moderate	Light
Aircraft Carriers	30	20	5
Battleships	45	25	5
Cruisers (heavy)	40	20	5
Cruisers (light) (AA)	30	20	5
Destroyers	25	15	5
Pontoons (for pier construction)	60	-	-
Transports	30	20	5
LSTs & Landing Craft and Landing Vehicles	25	15	5
Submarines (surfaced)	80	60	-

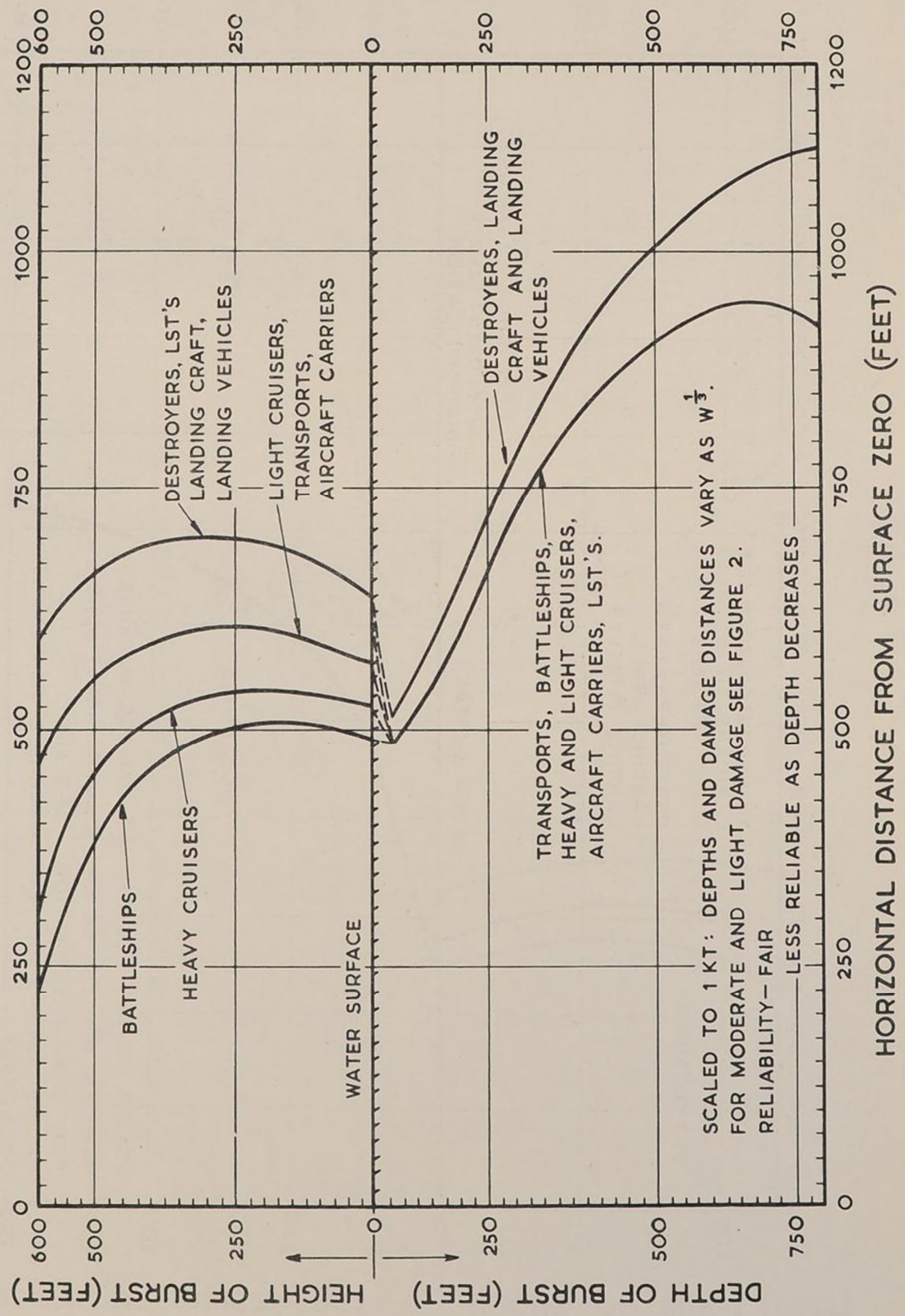
The damage levels are defined as follows:-

Severe - (Probable sinking). The ship is sunk or is damaged to the extent of requiring rebuilding.

Moderate - (Immobilisation) The ship requires extensive repairs. This includes damage to certain shock-sensitive components or to their foundations, such as propulsion machinery, boilers, and damage to interior equipment.

Light - This category includes damage to electronic, electrical and mechanical equipment; however, the ship may still be able to operate effectively.

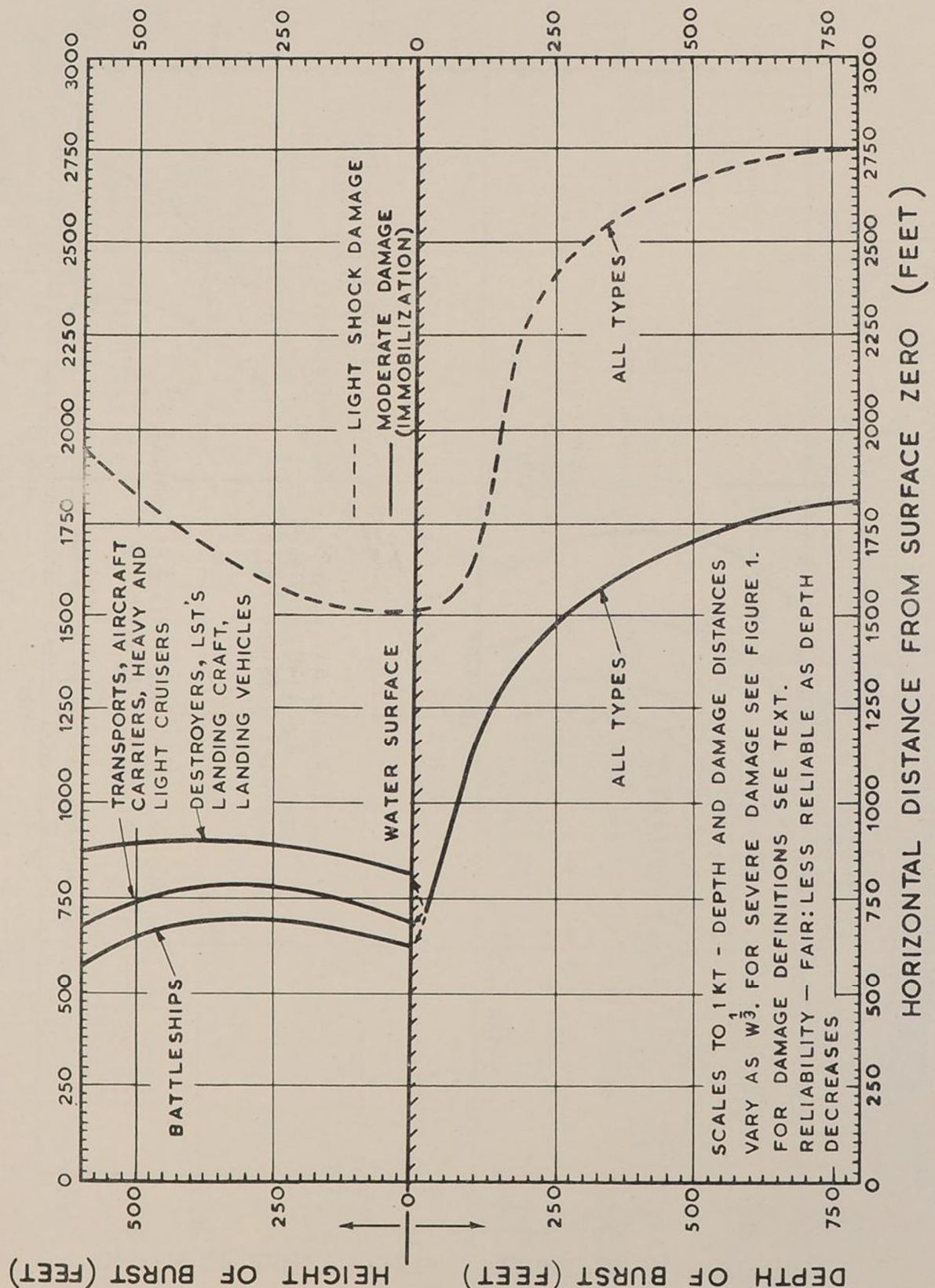
* Note: this information is of American origin, whereas British estimates (L.C.A.F.O.117/55) indicate somewhat greater damage radii corresponding to less severe pressure criteria.



SEVERE DAMAGE TO SURFACE SHIPS
(PROBABLE SINKING)

PART III
CHAPTER 9
SECTION 9.7.1.
FIGURE 2

SECRET ATOMIC



MODERATE AND LIGHT DAMAGE TO SURFACE SHIPS

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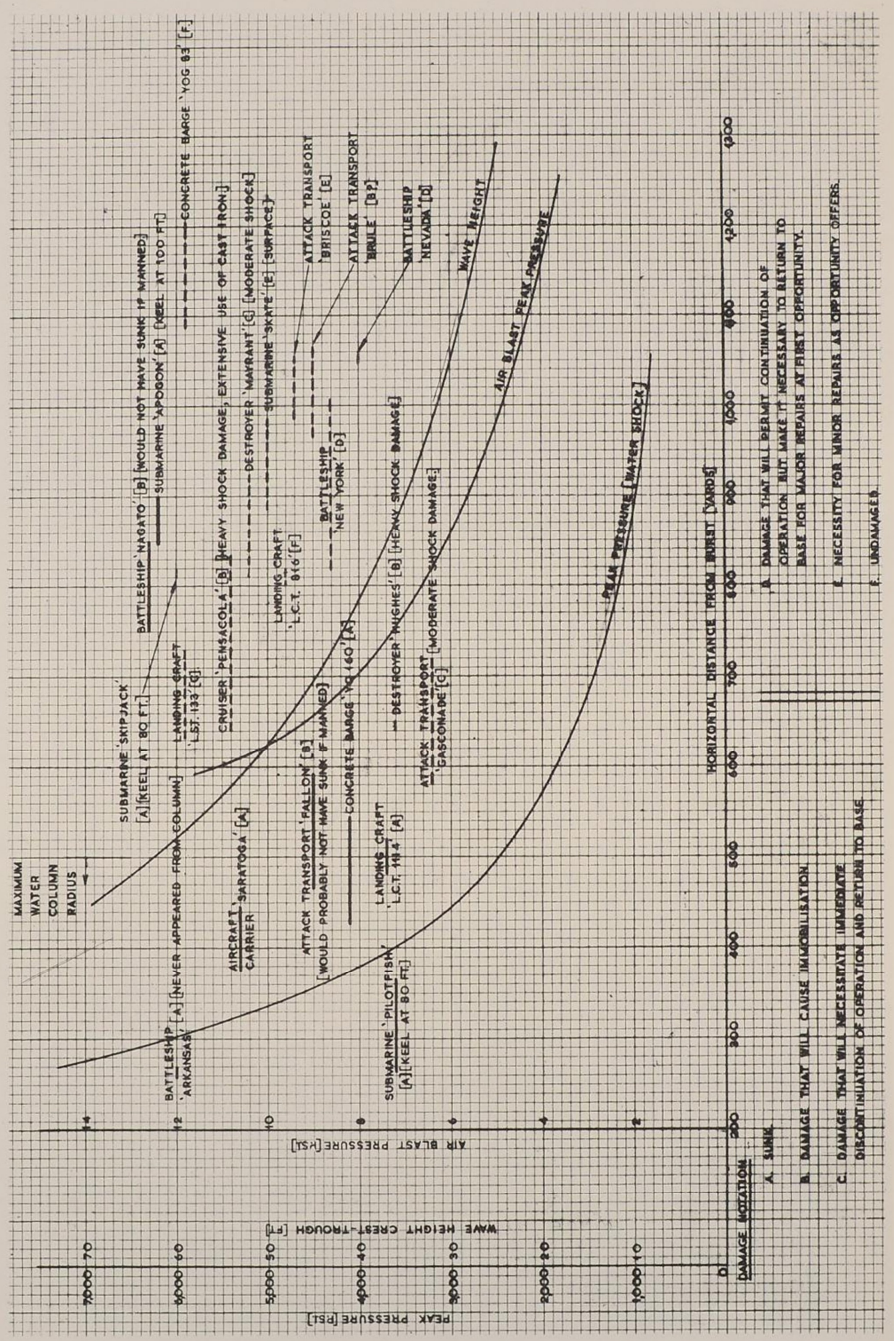


DATA FROM BIKINI

SHOT BAKER

3.8 The Effect of Surface Waves on Surface Ships

At the ranges at which the underwater shock wave can do considerable damage the surface waves produced by underwater atomic explosions can be very large. The mechanism of wave formation is discussed in the British "Manual on the Effects of Atomic Weapons" where the following simple formulae are given for wave height etc.

$$\text{Wave height (Crest to Trough) (ft.)} = (4.9)10^4 W^{1/2}/H \quad (13)$$
$$\text{Wave length (ft.)} = 750\ W^{1/4} \quad (14)$$
$$\text{Group Velocity (ft./sec.)} = 31 W^{1/8} \quad (15)$$

where W is the Radio-Chemical Yield expressed in Kilotons of T.N.T. and a bubble equivalent energy of 0.86 W is assumed; H is the horizontal distance from ground zero (ft.). The above wave heights etc. apply when the weapon is exploded near to its venting depth given by

$$V = 240\ W^{1/4}\ \text{(ft.)} \quad (16)$$

For shallower and greater depths of explosion the wave heights will be somewhat smaller except that for bursts very near the surface slightly larger waves may result.

It is of interest to examine the wave properties at the ranges of interest from the viewpoint of shock wave damage. Assuming that a value of $d/E = 7.10^{-4}$ is lethal for shock wave damage (see Section 3.3), the maximum horizontal range for sinking is given by -

$$H_{max} = 840\ W^{1/3} \quad \text{(assuming a shock wave equivalent weight of } \tfrac{2}{3} W) \quad (17)$$

This maximum horizontal range is obtained for a depth of explosion -

$$D_{max} = 570\ W^{1/3} \quad (18)$$

At the range H_{max} the maximum wave height H_W is given by $H_W = (58.4)\ W^{1/6}$ (19) if the explosion takes place at a depth V where -

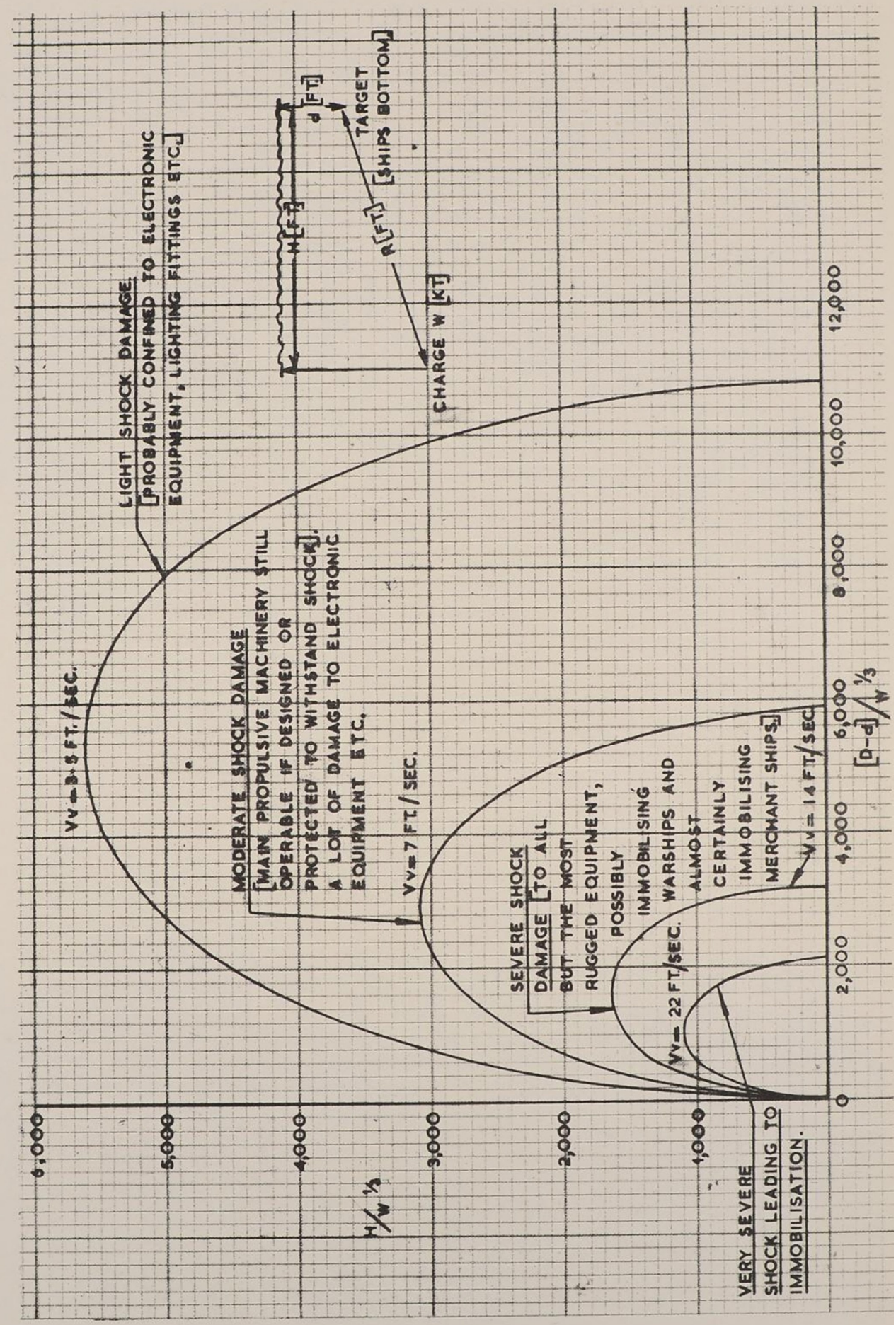
$$D_{max}/V = (2.37)\ W^{1/12} \quad (20)$$

Numerical examples for several cases of interest are given in Table (I).

Section 3.8 Table (I)

Radio-Chemical Yield	Maximum Wave Height at Shock Wave Sinking Range (Crest to Trough) (ft.)	Wave Length (ft.)	Group Velocity (ft./sec.)	$\left(\frac{D_{max}}{V}\right)$
1 Kiloton	58	750	31	2.37
20 Kilotons	97	1,600	45	3.03
1 Megaton	185	4,200	74	4.22
20 Megatons	300	8,900	109	5.5

Ships are usually designed to have acceptable bending stresses when sitting symmetrically in quasi static equilibrium on a trochoidal wave with



SHOCK DAMAGE CURVES
FOR SURFACE SHIPS

CHAPTER 4 - DAMAGE MECHANISMS FOR SUBMERGED SUBMARINES

4.1 The Types of Damage

The damage to submarines caused by underwater explosions from conventional and atomic weapons falls into two fairly distinct types. Firstly the general shaking up of the submarine caused by the shock wave can cause machinery to be displaced or damaged so as to impair the operation of the submarine sufficiently, in severe cases, to cause complete loss. This type of damage is generally referred to as shock damage and can be reduced by the improved design of machinery and mountings. No matter how shock resistant a submarine is made, however, a point is reached as the charge standoff is reduced when hull splitting or gross deformation results which will usually result in the complete loss of the submarine. The standoff at which this occurs, often referred to as the lethal radius, is of particular interest and will be considered first.

The problem is one of considerable difficulty and several lethality criteria based on entirely different collapse mechanisms have been suggested and are more or less tenable. As all of the criteria are based on highly simplified mathematical models, their validity depends upon their agreement with experimental results. Unfortunately insufficient experimental results are available at present to enable any of the criteria to be rejected. These criteria will be described briefly with a discussion of their shortcomings.

4.2 The Mechanism of Hull Splitting

For a deep burst against a deep submarine, when surface cutoff can be neglected, the shock wave from an atomic explosion is quite long compared to the diametral or compartment length of a submarine. This is illustrated in figure (1), where the pressure distance relationship for the shock wave from an explosion of 1.5 K.T., 30 K.T. and 1.5 M.T. Radiochemical Yield is given for the ranges corresponding to a peak pressure of 1,000 p.s.i. The pressure decays rather little over a range equal to a diameter or compartment length, so the submarine is soon bathed in an almost uniformly high pressure which decays exponentially with time. Since the time constant of the decay is several times greater than the natural period for hull radial vibrations, this may suggest at first sight that when cutoff is not important, the loading may be considered as effectively static. Thus it may be expected that collapse will occur when

$$P_m + P_o = P_c$$

where

P_m is the peak shock wave overpressure
P_o is the hydrostatic pressure at the depth of the submarine
P_c is the static collapse pressure of the submarine.

The problem is not so simple however for the following reasons;

(a) The question of a dynamic factor has to be considered since the loading is suddenly applied. If, as for linear springs under suddenly applied constant loading, the dynamic factor is 2 then yielding and possibly collapse could occur when

$$2 P_m + P_o = P_c$$

/(b)

9.9. VEGETATION

9.9.1. Introduction

Although forests or tree stands may afford troops deployed in them significant protection against certain effects of atomic bomb detonation (e.g. thermal radiation), the forests themselves are quite vulnerable to some of these effects. Falling limbs and trees create a missile hazard, and the resultant debris on the forest floor may impede the movement of troops and most vehicles. In dry, windy weather, forest fires may be initiated by an atomic bomb detonation, with smoke and flame extending the range of hazardous effects from the bomb itself many times. Forest vulnerability depends on recent local weather history and upon the type of tree stand involved. Forest kindling fuels and types of stand are discussed in the paragraphs which follow from the blast damage point of view only. Thermal aspects of the problem are dealt with in Part VI.

9.9.2. Types of Forest Stand

For convenience in discussion of blast effects, forest stands are divided into three types.

Type I Stand - Improved natural or planted conifer forests of European Type.

These forests characteristically grow in regular blocks usually with definite borders. Tree spacing is uniform, with only small patches of ground visible through the canopy from above. Trees are of uniform height and nearly the same diameter. Viewed from above, the crown canopy appears smooth. Within the stand there usually are found low stumps resulting from thinning, clear lower stems as a result of pruning, and little or no underbrush, combining to give the interior of the stand a clear appearance and affording good visibility and easy passage into the forest.

Type II Stand - Naturally Occurring Unimproved Conifer Forests that developed under Unfavourable Growing Conditions -

Unfavourable growing conditions result from shallow rocky soil, deficiant annual rainfall, short growing season with unfavourable temperatures (i.e. higher altitudes or higher elevations), and unfavourable temperatures (i.e. higher altitudes or higher elevations), and unfavourable topography such as poorly drained flats or steep slopes. Random tree spacing is a characteristic, with all tree sizes represented. The crown canopy generally has an uneven appearance. Large stands often contain bare areas with irregular borders.

Type III Stand - All Broad Leaf Forests, and Naturally Occurring Unimproved Conifer Forests, that have developed under Favourable Growing Conditions -

Favourable growing conditions are associated with deep, generally rock-free soil; adequate annual rainfall; long growing season with favourable temperatures (i.e. middle latitudes and lower elevations); and favourable topography such as well-drained flats and moderate slopes, or along stream courses. Random tree-spacing is characteristic, with all tree sizes represented. The crown canopy is generally uneven in outline. Large stands often contain bare areas with irregular borders. Tree crowns and vegetation in general are vigorous in appearance.

9.9.3 Damage Criteria - Height of burst/damage distance curves for severe and light damage by air blast are presented in Figures 1, 2 and 3. The tree stand types referred to are those given above. Severe and light damage are defined in terms of length of stems down per acre, approximately 1500 ft. per acre for light damage and 9,000 ft. per acre for severe damage. These criteria are shown in terms of percentage of trees broken in Table I. The approximate number of trees per acre that may be expected for the three types of forest stand is also shown.

TABLE I - Percentage of Trees Broken for Light and Severe Damage to Forest Stands

Stand type	Trees per Acre	Light damage percent of trees broken	Severe damage percent of trees broken
I	75	15	90
II	260	10	60
III	200	10	60

SECRET ATOMIC

PART III
CHAPTER 9
SECTION 9.9.3.
FIGURE 1 A & B

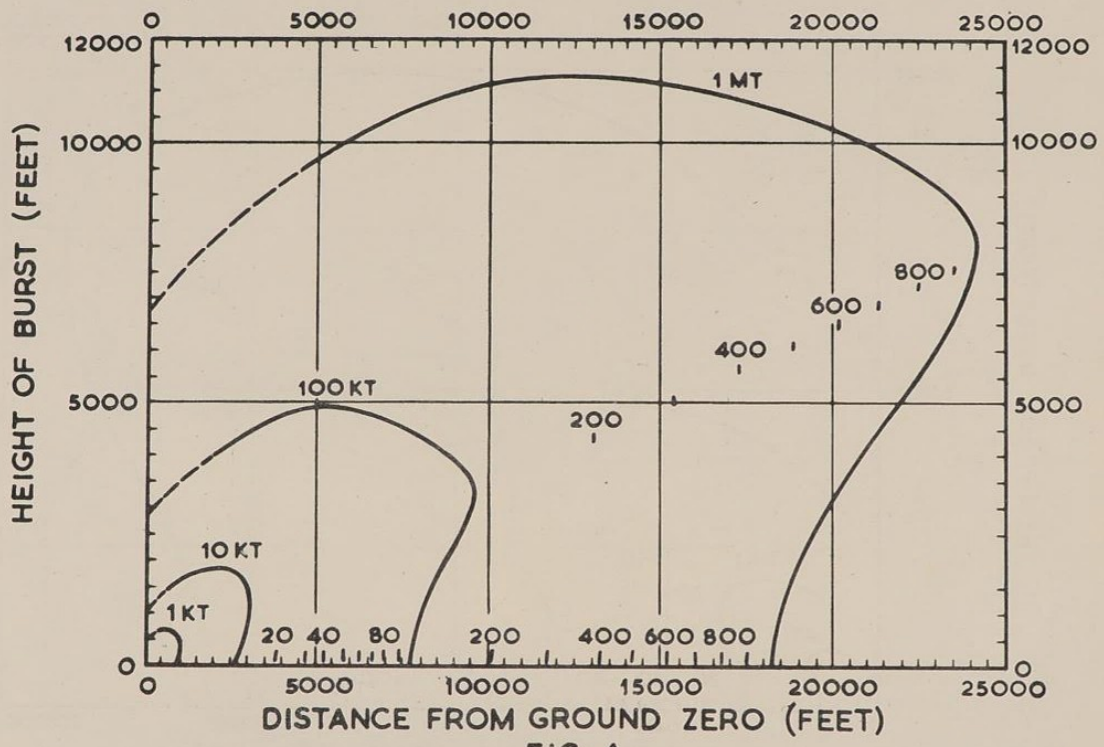


FIG. A

SCALE 1 MT CURVE WITH $W^{\frac{1}{3}}$ FOR LARGER YIELDS.
FOR DAMAGE DEFINITIONS SEE TEXT.
RELIABILTY – GOOD.

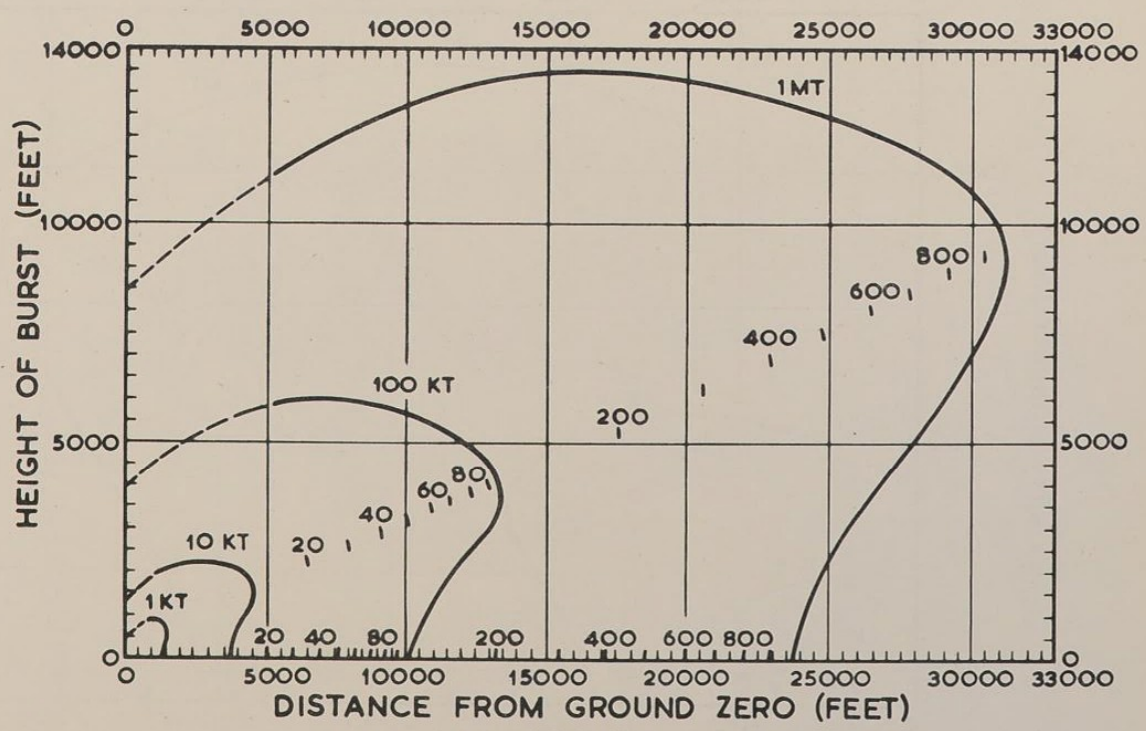


FIG. B

FIG. A. SEVERE DAMAGE TO TYPE I FORESTS
FIG. B. LIGHT DAMAGE TO TYPE I FORESTS

PART III
CHAPTER 9
SECTION 9.9.3.
FIGURE 2 A & B

SECRET ATOMIC

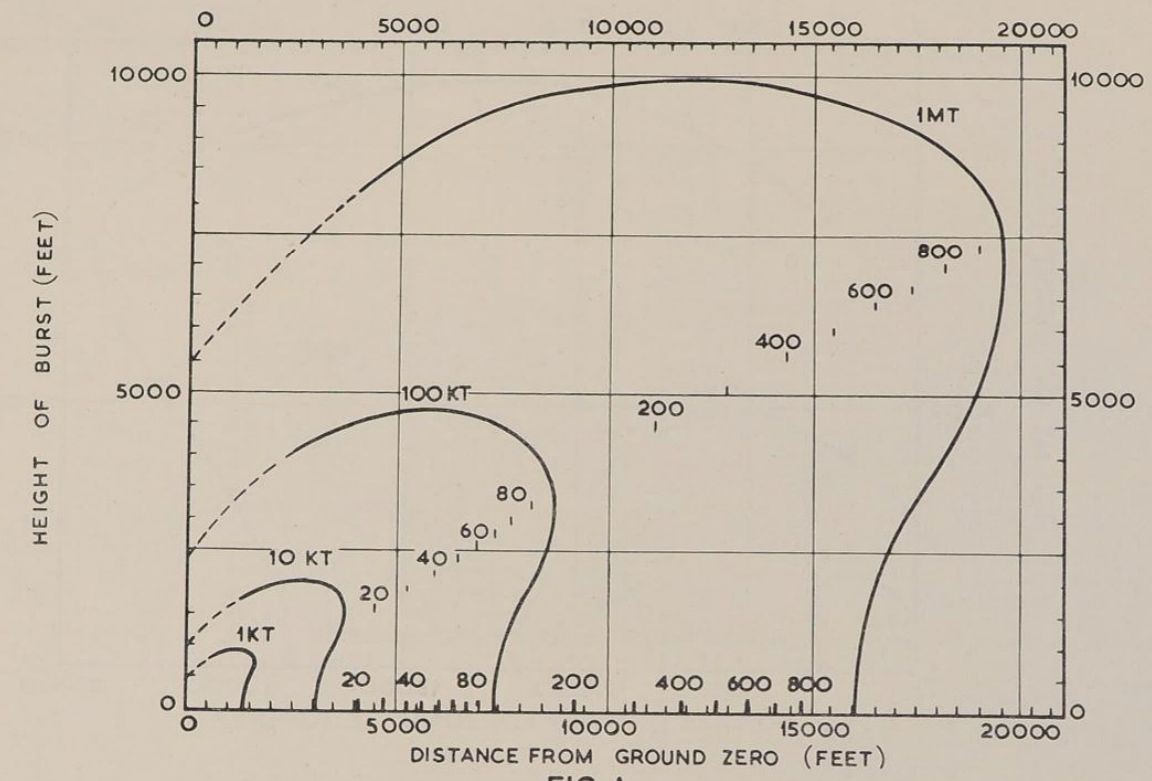


FIG. A

SCALE 1MT CURVE WITH $W^{1/3}$ FOR LARGER YIELDS. FOR DAMAGE DEFINITIONS SEE TEXT. RELIABILITY – GOOD.

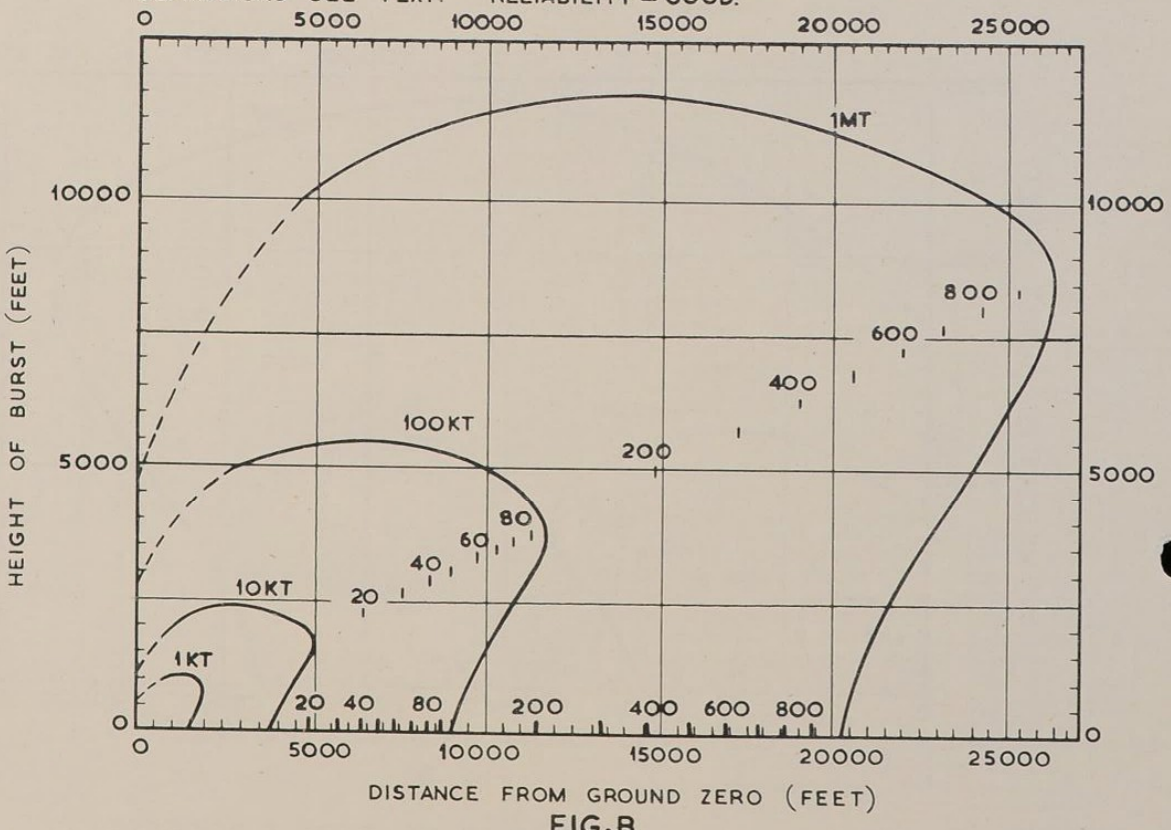


FIG. B

FIG. A. SEVERE DAMAGE TO TYPE II FORESTS
FIG. B. LIGHT DAMAGE TO TYPE II FORESTS

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SECRET ATOMIC

PART III
CHAPTER 9
SECTION 9.9.3.
FIGURE 3 A&B

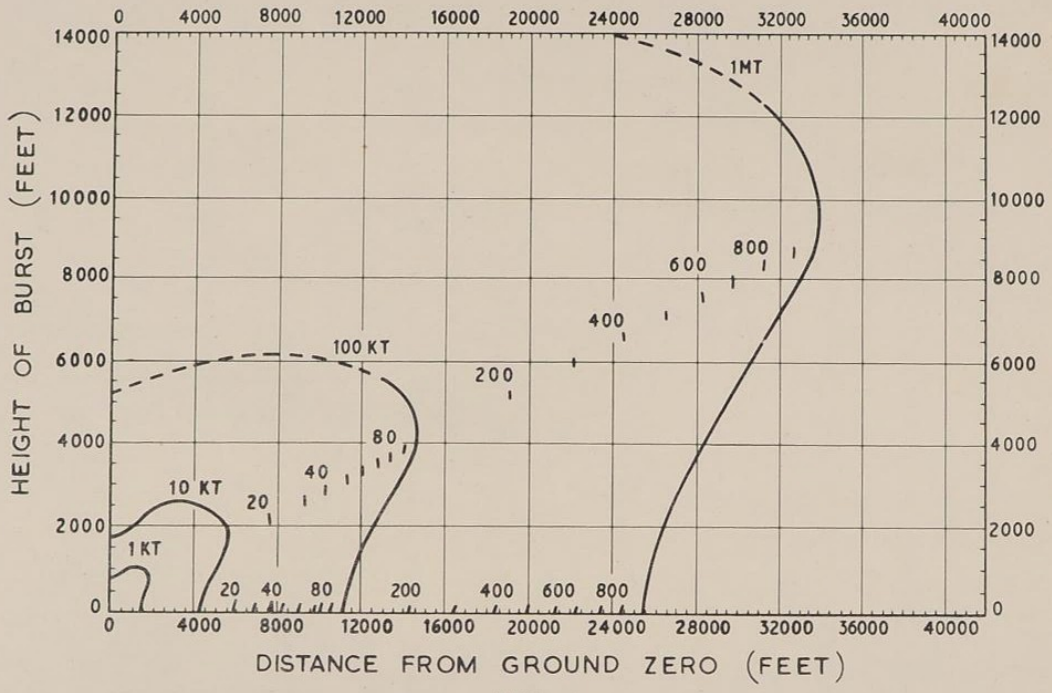


FIG. A

SCALE 1 MT CURVE WITH $W^{\frac{1}{3}}$ FOR LARGER YIELDS. FOR DAMAGE DEFINITIONS SEE TEXT. RELIABILITY — GOOD

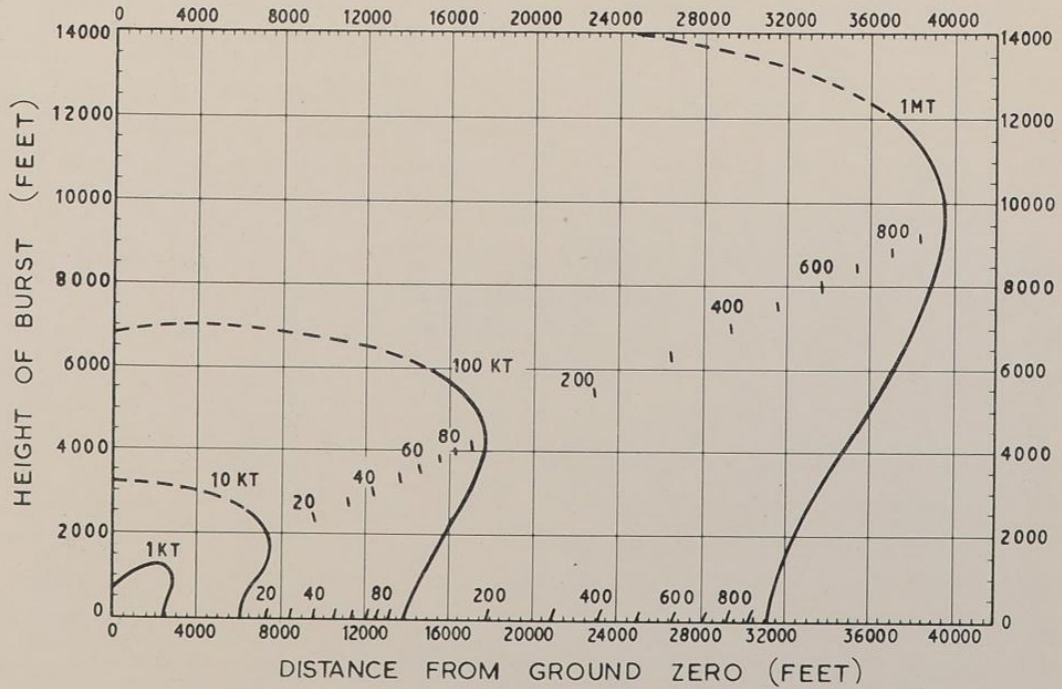


FIG. B

FIG. A. SEVERE DAMAGE TO TYPE III FORESTS
FIG. B. LIGHT DAMAGE TO TYPE III FORESTS

9.2.8. Bridges. Damage to bridges by bursts at low heights (up to $400W^{\frac{1}{3}}$ ft.) is shown in Figure 1 for yields from 0.1 KT to 100 MT. The curves apply to highway and railway truss bridges for orientations of blast propagation from 45° to 90° from the longitudinal bridge axis. The given distances of Figures 2 and 3 are to be reduced to 60% for an orientation of 0° for all span lengths. In the case of orientations between 0° and 45° a linear interpolation is to be used.

The damage curves of Figure 4 apply to floating bridges types M-2 or M-4 at all orientations.✓ Typical examples of severe, moderate and light damage are given in Table I of Section 9.1.4. The adaptation of these curves to give other damage levels or probabilities of damage is described in Section 9.1.5. The allowances to be made in the case of airblast damage from underground bursts are given in Section 9.1.6.

✓ Note. Details of the U.S. Army standard floating bridges M-2 and M-4

M-2 - Capacity 44 tons safe, 50 tons risk, corresponds roughly to Class 40 safe and Class 50 for risk respectively. Two steel treadway tracks $45\frac{1}{2}$ in. wide with 63 in. gap. Rubber pneumatic floats of 24 tons total buoyancy at a centre spacing of 12 ft.

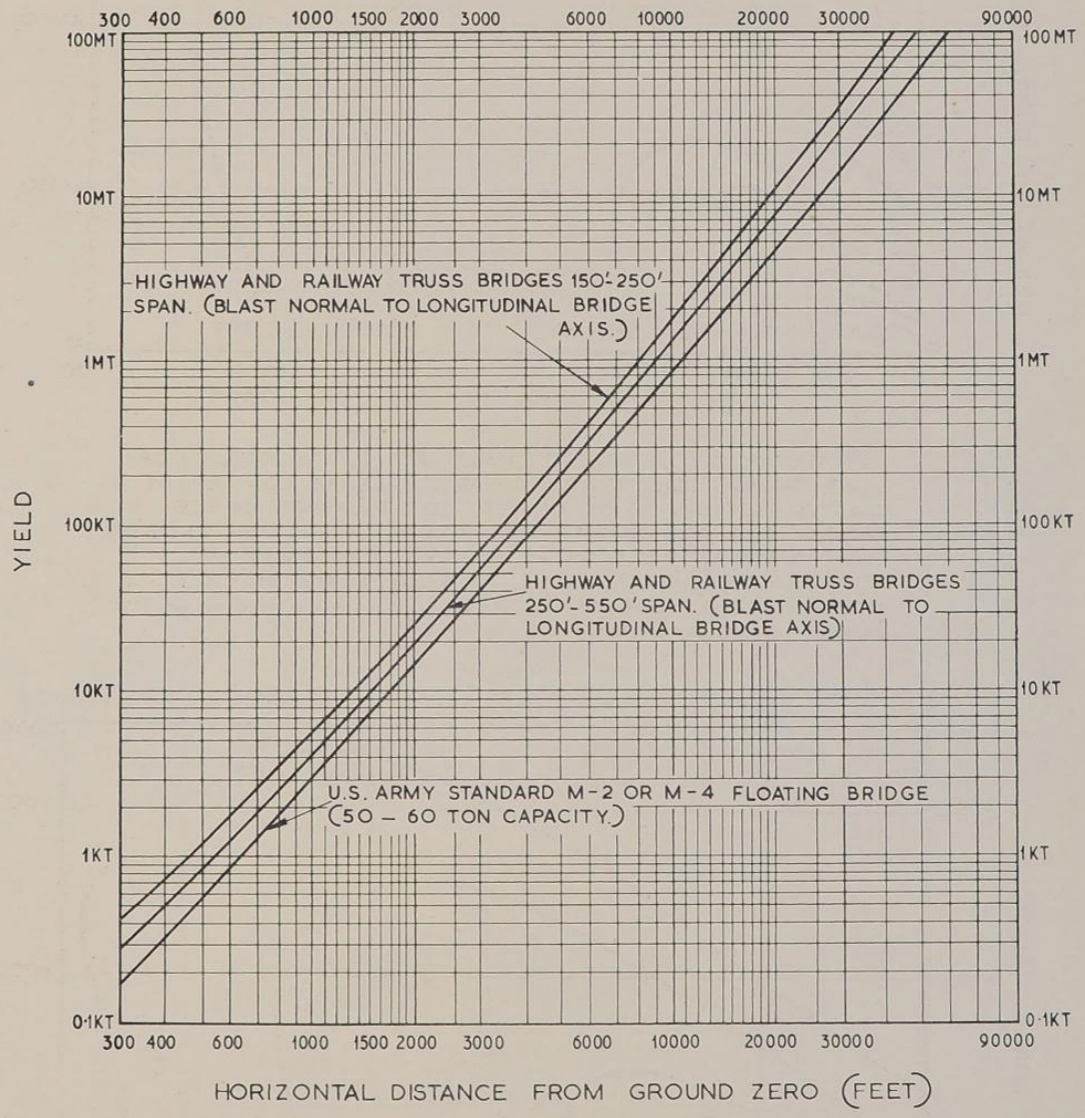
M-4 - Capacity roughly Class 50. Full width roadway of longitudinal aluminium baulks, carried on light alloy or steel open pontoons.

9.2.9. Oil Storage Tanks - The oil storage tanks for which damage curves are given in Figure 1 were 30 ft. high and 50 ft. in diameter. Empty tanks would be considerably more vulnerable and would probably suffer severe damage at ranges where only moderate or light damage would result when full. Typical examples of severe, moderate and light damage are given in Table I of Section 9.1.4. The adaptation of these curves to give other damage levels or probabilities of damage is described in Section 9.1.5. The allowances to be made in the case of airblast damage from underground bursts are given in Section 9.1.6.

SECRET ATOMIC

PART III
CHAPTER 9
SECTION 9.2.8.
FIGURE 1

BURST HEIGHT BETWEEN ZERO AND $400 W^{\frac{1}{3}}$ FEET.
50% PROBABILITY OF SEVERE DAMAGE. TO CONVERT TO OTHER CRITERIA SEE SECTION 9.1.5. FOR DAMAGE DESCRIPTIONS SEE SECTION 9.1. TABLE 1



DAMAGE TO BRIDGES BY BURSTS AT LOW HEIGHTS

PART III
CHAPTER 9
SECTION 9.2.8.
FIGURE 2 & 3

SECRET ATOMIC

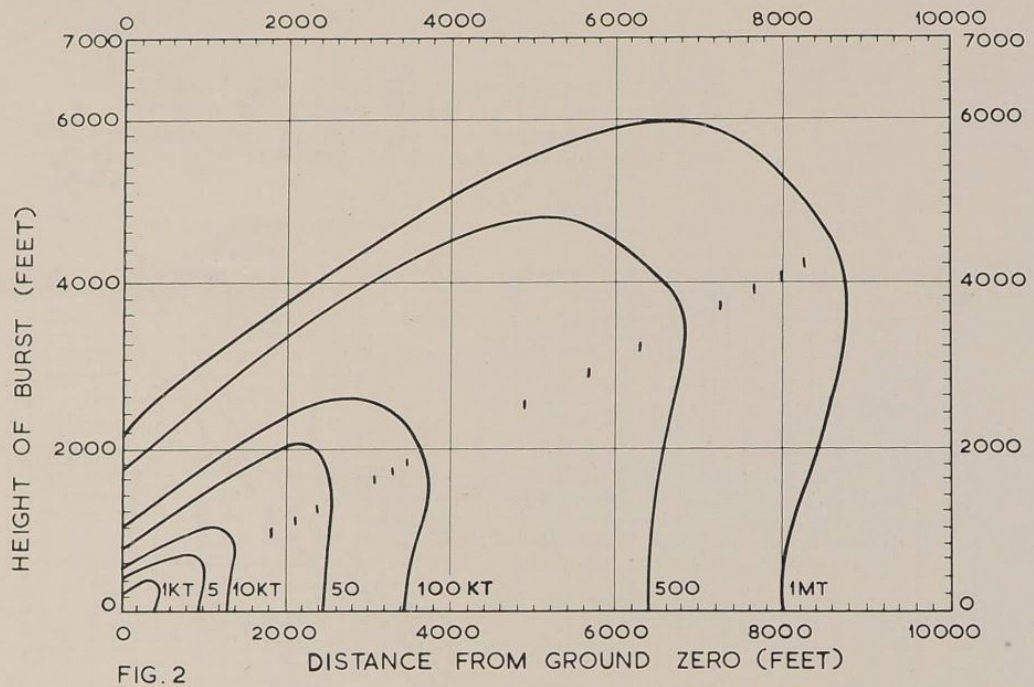


FIG. 2

50% PROBABILITY OF SEVERE DAMAGE. FOR 50% PROBABILITY OF LIGHT DAMAGE SCALE 0·6.P.S.I. DYNAMIC PRESSURE CONTOUR IN CHAPTER 1, SECTION 1.1. TO CONVERT TO OTHER CRITERIA SEE SECTION 9.1.5. FOR DAMAGE DESCRIPTIONS SEE SECTION 9.1.TABLE 1. BLAST STRIKING BETWEEN 45° AND 90° TO LONGITUDINAL AXIS OF BRIDGE. FOR ORIENTATIONS BETWEEN 0° AND 45°, INTERPOLATE LINEARLEY BETWEEN 60% AND 100% OF THE DAMAGE RANGES SHOWN

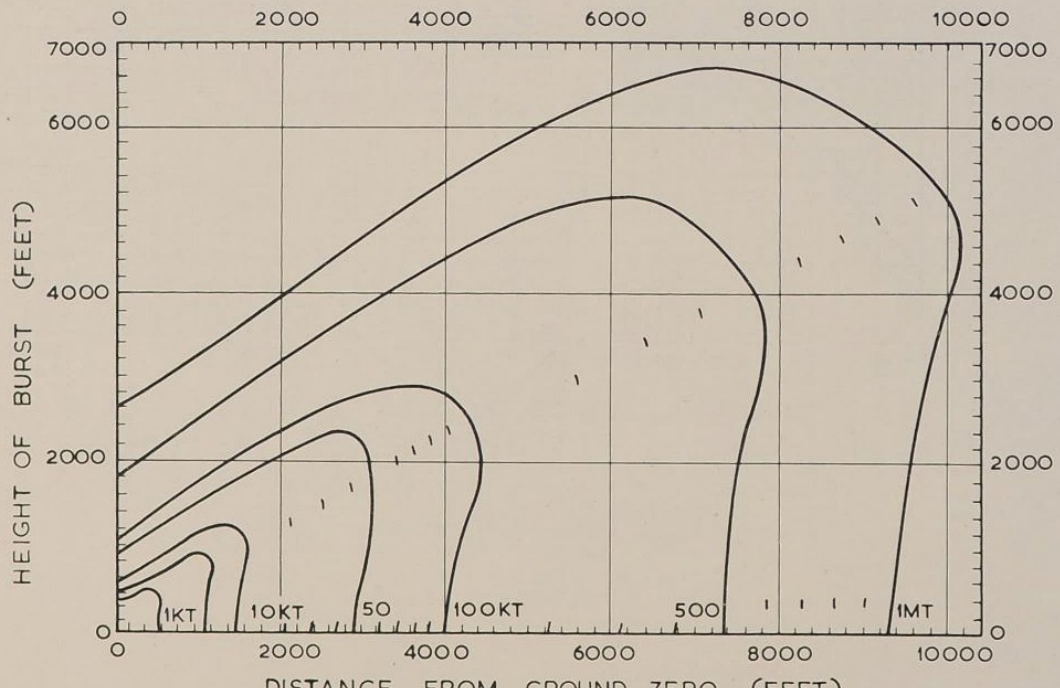


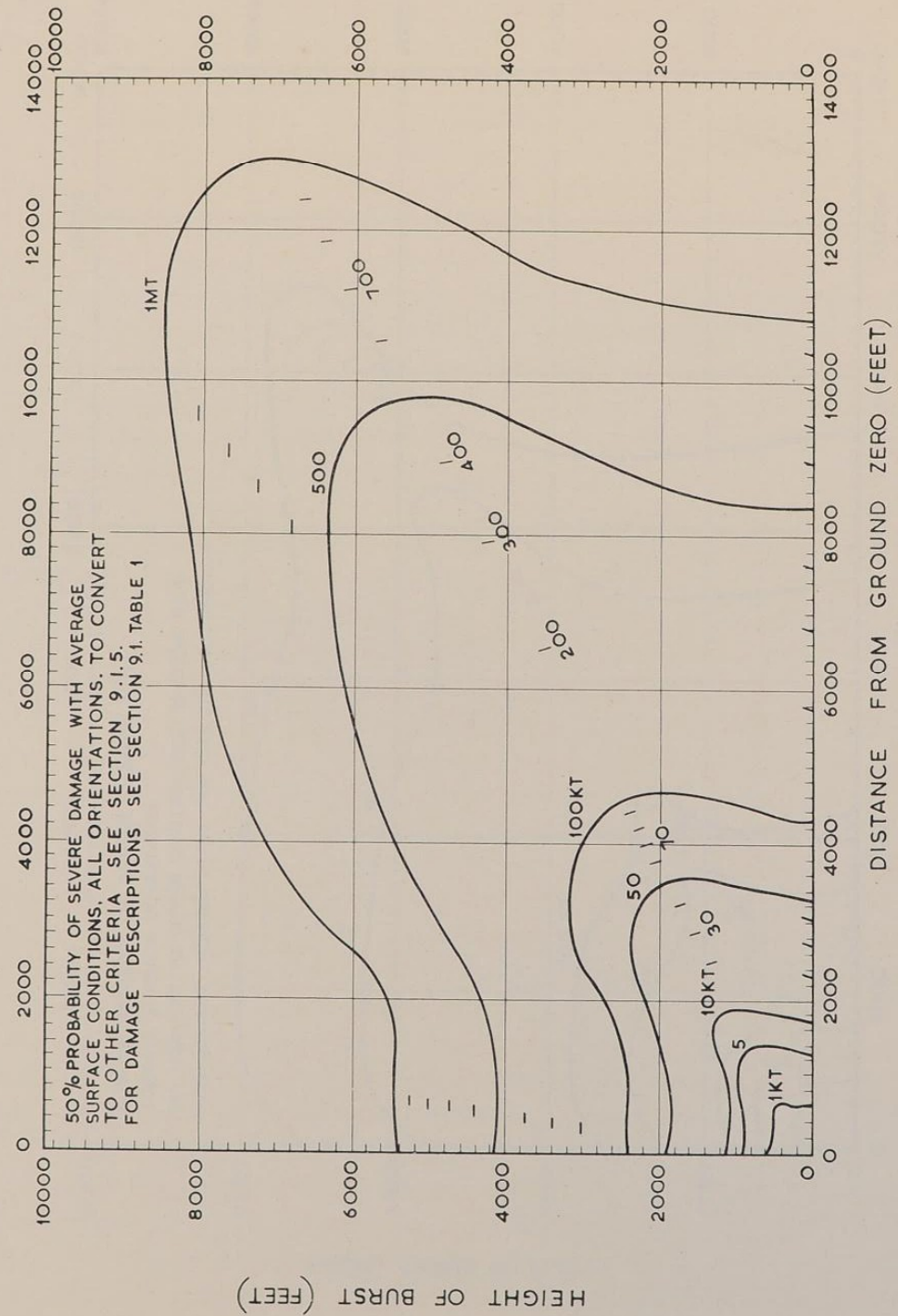
FIG.3

FIG. 2 DAMAGE TO TRUSS BRIDGES OF 150'-250' SPAN.
FIG. 3 DAMAGE TO TRUSS BRIDGES OF 250'-550' SPAN.

SECRET ATOMIC

SECRET ATOMIC

PART III
CHAPTER 9
SECTION 9.2.8.
FIGURE 4



DAMAGE TO FLOATING BRIDGES
TYPES M-2 OR M-4

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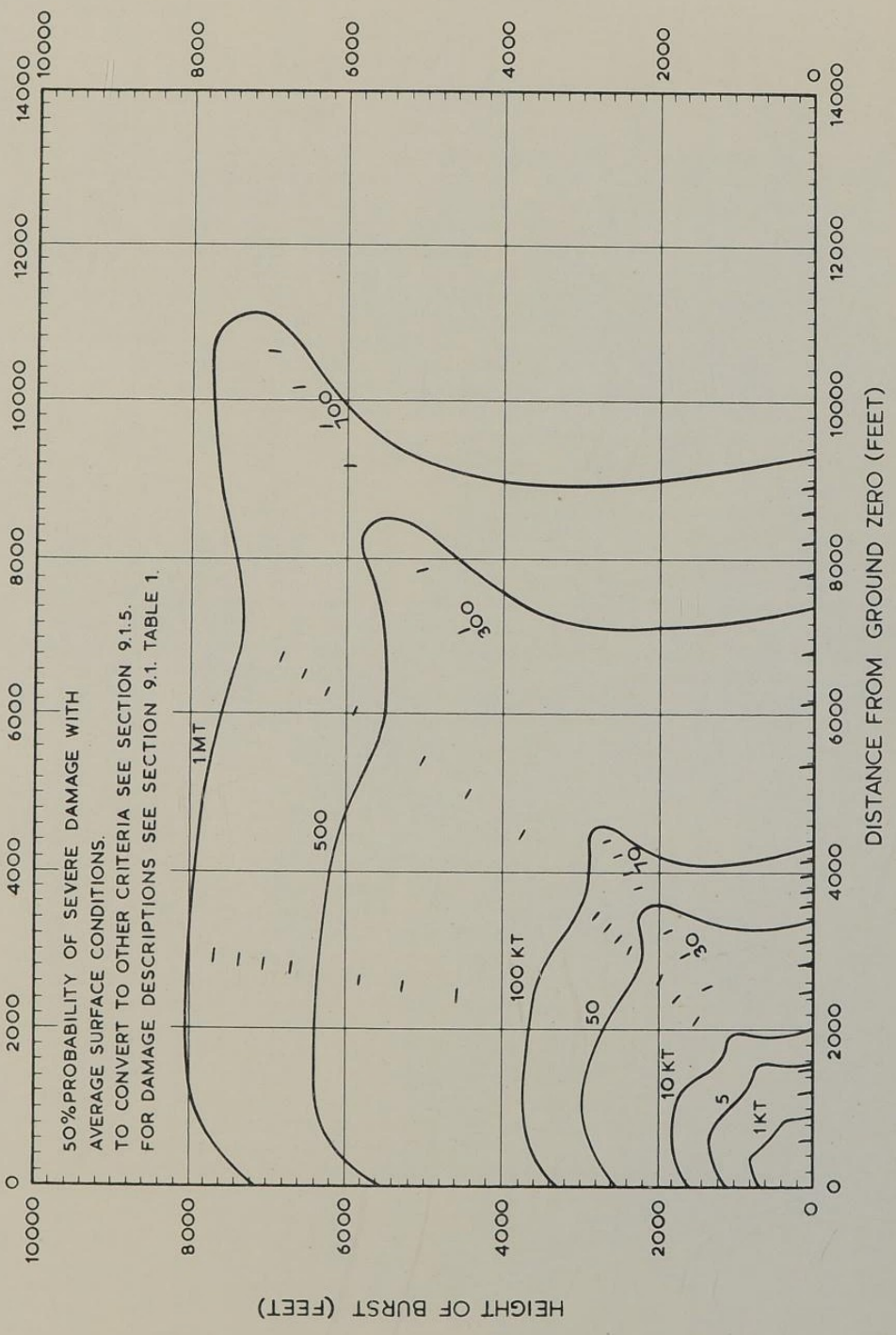
SECRET ATOMIC

PART III
CHAPTER 9
SECTION 9.2.9.
FIGURE 1



DAMAGE TO FILLED OIL STORAGE TANKS

CONFIDENTIAL

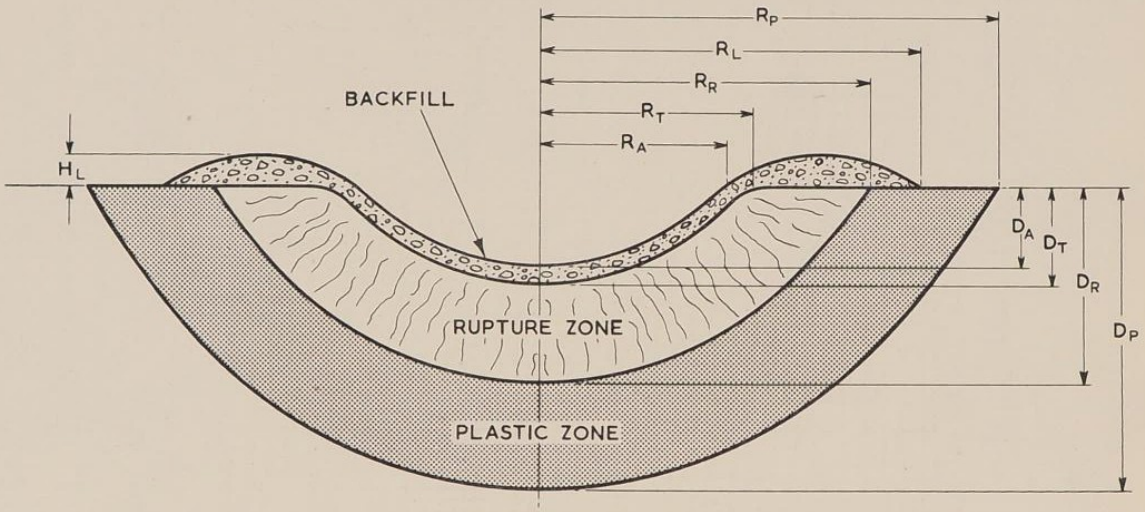
PART IV
CHAPTER 1
SECTION 1.2
FIGURE 3

NOTE:–

CRATER RADII ARE MEASURED AT THE ORIGINAL GROUND LEVEL.

CRATER DEPTHS AND LIP HEIGHTS ARE MEASURED RELATIVE TO THE ORIGINAL GROUND LEVEL.

UNCERTAINTIES OF TERRAIN TEND TO MASK THE DISTINCTION BETWEEN TRUE AND APPARENT DIMENSIONS. WHEN NO DISTINCTION IS FEASIBLE, R_C AND D_C ARE USED FOR CRATER RADIUS AND DEPTH RESPECTIVELY.



R_A = APPARENT RADIUS OF CRATER, INCLUDING BACKFILL.

R_T = TRUE RADIUS OF CRATER WITHOUT BACKFILL.

R_R = RADIUS OF RUPTURE ZONE, APPROXIMATELY $1{\cdot}5\ R_A \pm 25\%$

R_L = RADIUS OF OUTER LIP OF CRATER, APPROXIMATELY $2\ R_A \pm 25\%$

R_P = RADIUS OF PLASTIC ZONE, SOMEWHAT GREATER THAN R_L FOR MOST SOILS BUT PRACTICALLY NON-EXISTENT FOR ROCKS.

H_L = HEIGHT OF LIP OF CRATER, APPROXIMATELY $0{\cdot}25\ D_A \pm 50\%$

D_A = APPARENT DEPTH OF CRATER, INCLUDING BACKFILL.

D_T = TRUE DEPTH OF CRATER WITHOUT BACKFILL.

D_R = DEPTH OF RUPTURE ZONE.

D_P = DEPTH OF PLASTIC ZONE.

V_A = APPARENT VOLUME OF CRATER (ASSUMED PARABOLOIDAL)
$= \pi\ R_A^2 .\ D_A / 2.$

V_T = TRUE VOLUME OF CRATER (ASSUMED PARABOLOIDAL)
$= \pi\ R_T^2 .\ D_T / 2.$

V_R = VOLUME OF RUPTURE ZONE.

V_P = VOLUME OF PLASTIC ZONE.

CRATER PARAMETERS

2.2 Free Earth Pressures

Note.- For list of symbols see Preliminary, Page 2, of this Part.

In this section the pressures set up in the ground remote from any structure are described. The most detailed series of measurements of earth pressures was carried out in America by Lampson - Reference (1). Applying his results, which were obtained using H.E. charges, to atomic weapons, we may write the pressure (p) at distance R for depths greater than about 200 $W^{\frac{1}{3}}$ feet, as:-

$$p = FkWR^{-3} \qquad 2.2.1$$

This pressure is of the nature of an added hydrostatic pressure. The variation of the coupling factor (F) with scaled weapon depth is shown in Figure 1. This curve is only approximate, since it has been necessary to incorporate very uncertain data on explosive equivalence as a function of depth. The soil constant (k) varies widely from soil to soil and depends on the state of any given soil (e.g. moisture content) at the time of the explosion. The value of the constant was found to be correlated with the velocity of compressional waves in the ground, the so-called seismic velocity, by the relation:-

$$k = 2.5\rho v_T^2 \qquad 2.2.2$$

A list of soil constants is given in Table I for some typical soils.

TABLE I - Typical Soil Constants

Soil Type	Pressure Constant, k	Impulse Constant, B
Loess	2.2×10^8	4×10^6
Loam	5.6×10^8	12×10^6
Silty Clay	1.4×10^9	14×10^6
Clay-unsaturated	4×10^9	16×10^6
Clay-saturated	2.8×10^{10}	16×10^6

The pressure wave consists essentially of a single pulse, the shape and duration of which vary with distance from the weapon. The parameter which takes into account the pressure, duration, and shape of the pulse, is the impulse, which is defined as:-

$$I = \int_0^\tau p.dt$$

Lampson's results applied to nuclear explosions may be written in the form:

$$I = FBW^{7/6} R^{-5/2} \qquad 2.2.3$$

Values of the impulse constant (B) are given in Table I above for typical soils. B can be related to the seismic velocity (v_L), within an accuracy of 35% by the expression:-

$$B = 50\rho v_L \qquad 2.2.4$$

For generalised data on peak particle displacement, velocity, and acceleration as functions of distance from surface bursts, see M.E.A.W., Chapter 2, Data Sheet 2.4. Some full-scale British measurements at Maralinga are reported in Reference (4).

As the terrain at Maralinga is somewhat unusual, details of its physical characteristics have been derived from Reference (4), and are given in Table II.

Table II

P Physical Characteristics of the Rocks in the Geological Section at Maralinga

Depth of Layer	Type of Rock	Density gm/cc	Velocity (ft/sec.)		Characteristic Impedance for P Waves c.g.s. units	Young's Modulus c.g.s. units
			P Waves (longitudinal)	S Waves (transverse)		
0/15 feet	Travertine limestone	2.7	5500 to 8500	-	5.8×10^5	1.2×10^{11}
thence to 75-80 feet	Sand underlying Travertine	2.0	2200 to 2700	-	1.5×10^5	0.3×10^{10}
thence to 200 feet	Sand and Clay	2.2	4300	-	2.9×10^5	2.7×10^{10}
thence to 1800 feet	Sandstone and/or Shales	2.5	11000 to 12000	8300 to 8600	8.8×10^5	3.1×10^{11}
tens of miles	Granite or Metamorphic Basement or limestone	2.7	19000	-	15.8×10^5	7.7×10^{11}

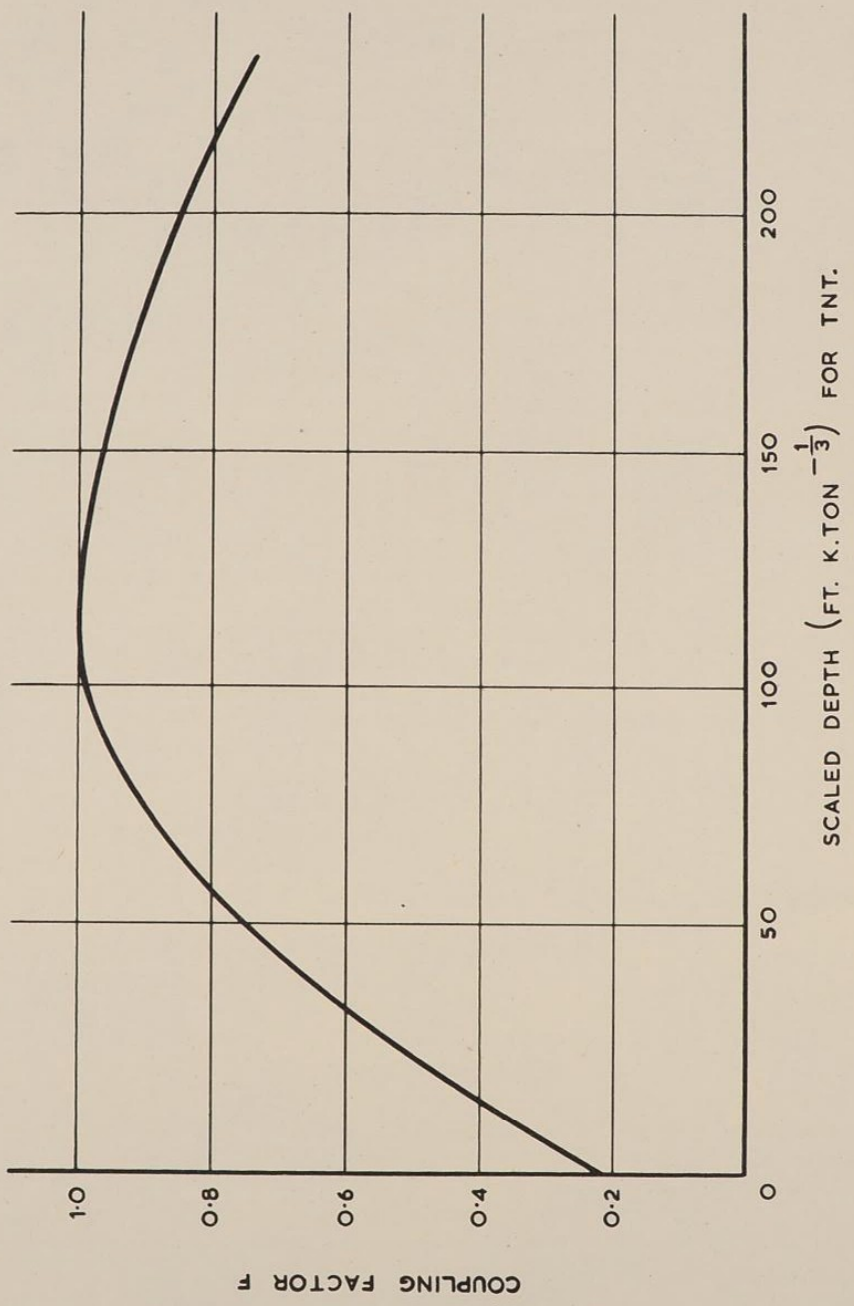
References

(1) Final Report on Effects of Underground Explosions, C.W. Lampson. N.D.R.C. Report No. A-479. O.S.R.D. Report No. 6645, March, 1946.

(2) Effects of Atomic Weapons. U.S. Government Printing Office, 1950. pp.413-423

(3) Manual on The Effects of Atomic Weapons (Chapter 2). A.W.R.E. (Secret/Atomic/U.K. Eyes Only)

(4) Operation 'Buffalo'. Measurements of Ground Shock and Crater. A.W.R.E. Report T37/57. (Secret/Atomic)



HIGH EXPLOSIVE COUPLING FACTOR
AS A FUNCTION OF WEAPON DEPTH

PART IV
CHAPTER 3
SECTION 3.1
FIGURE 2

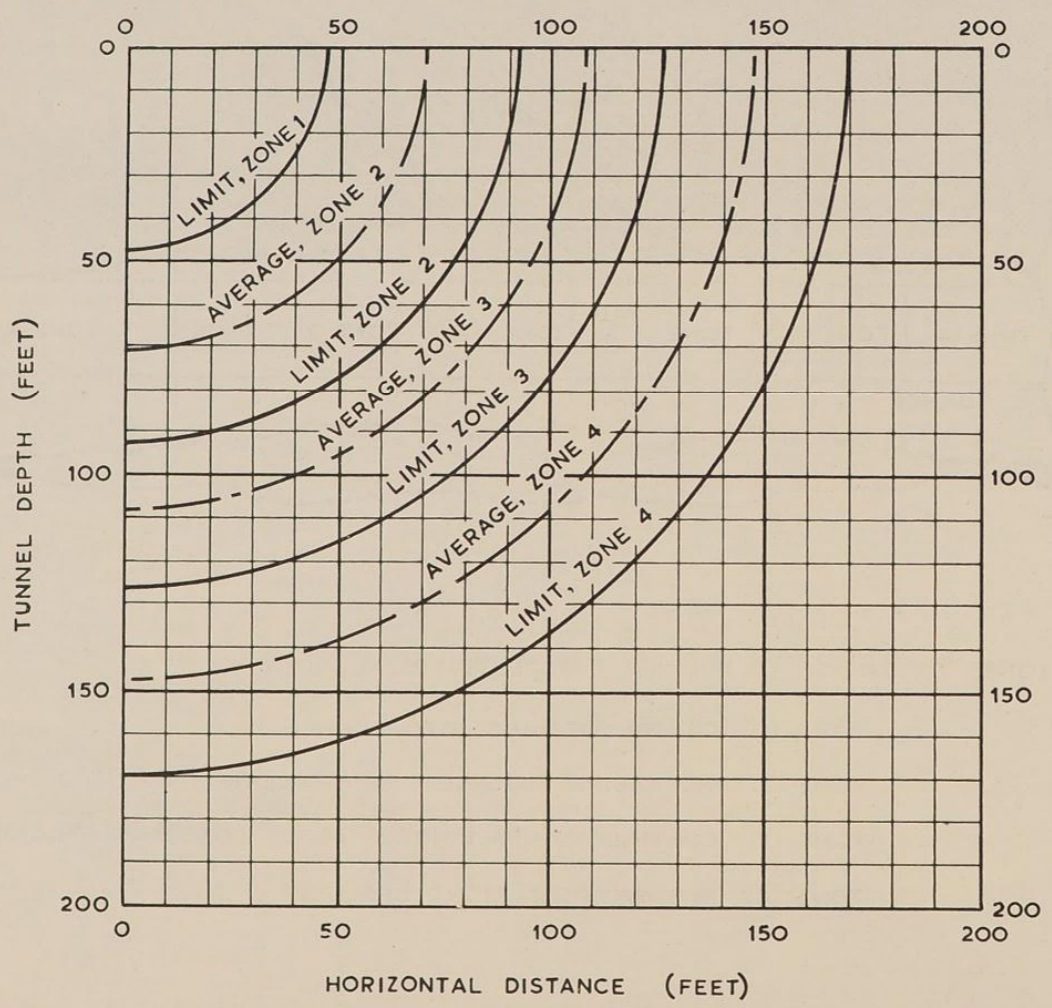
CONFIDENTIAL

CURVES REPRESENT 1 KT CONTACT SURFACE BURST.

TO OBTAIN DAMAGE DISTANCES FOR OTHER YIELDS, MULTIPLY TUNNEL DEPTH AND HORIZONTAL DISTANCE BY $W^{\frac{1}{3}}$.

FOR OTHER SOILS SEE TABLE 1.

FOR UNDERGROUND BURSTS SEE TEXT.



APPROXIMATE ISODAMAGE CONTOURS
FOR UNLINED TUNNELS IN ROCK

3.2 Damage Mechanisms

The wavelength of the stress waves near the centre of a nuclear explosion is of the order of 160 $W^{\frac{1}{3}}$ feet. Tunnels whose diameters were more than about six times this wavelength would act as almost perfect reflectors for the stress waves, so that the stress field close to the tunnel would approximate that near an infinite free surface. The stresses at the tunnel walls can be calculated from the laws of reflection of elastic waves, and the tunnel will collapse if these stresses exceed the breaking stress for the rock.

In the more usual case of tunnels whose diameters are several times smaller than the wave-length of the propagated stresses, very little energy is reflected at the tunnel surface and the tunnel is subjected to a quasi-static stress field. The stresses in this case are also calculable, and the same criterion for collapse applies.

3.2.1 Elastic wave reflection

When a plane compressional wave is reflected at normal incidence at an infinite free surface, the reflected wave is a tension pulse. For other angles of incidence transverse waves are generated in addition to the reflected longitudinal tension wave.

Notation:

i	=	Angle of incidence
r	=	Angle of reflection of the transverse wave
v_L	=	Velocity of propagation of the longitudinal wave
v_T	=	Velocity of propagation of the transverse wave
ν	=	Poisson's ratio
A_L	=	Amplitude of incident longitudinal wave
B_L	=	Amplitude of reflected longitudinal wave
B_T	=	Amplitude of reflected transverse wave.

The angle of reflection of the transverse wave is given by:-

$$\frac{\sin i}{\sin r} = \frac{v_L}{v_T} = \left[\frac{2(1-\nu)}{1-2\nu}\right]^{\frac{1}{2}} \qquad 3.2.1$$

The angle of reflection of the longitudinal wave is the same as the angle of incidence.

The amplitude of the reflected longitudinal wave, as a fraction of the incident wave, is given by:-

$$\frac{B_L}{A_L} = \frac{\sin 2i \sin 2r - (v_L/v_T)^2 \cos^2 2r}{\sin 2i \sin 2r + (v_L/v_T)^2 \cos^2 2r} \qquad 3.2.2$$

The amplitude of the reflected transverse wave as a fraction of the incident wave is given by:-

$$\frac{B_T}{A_L} = \frac{2(v_L/v_T) \sin 2i \sin 2r}{\sin 2i \sin 2r + (v_L/v_T)^2 \cos^2 2r} \qquad 3.2.3$$

These relations are shown graphically in Figure 1. If the incident stress is known, they suffice for the stresses at the tunnel wall to be calculated, and the extent of damage thereby predicted.

/Values

Table 1 - Modified Mercalli Intensity of 1931 (Abridged)

Intensity	Accelerarion	Effects
I	0.0006g	Not felt except by a very few under especially favourable circumstances.
II	0.0014g	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
III	0.003g	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognise it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.
IV	0.006g	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls made cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	0.014g	Felt by nearly everyone; many awakened. Some dishes, windows and so forth broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.
VI	0.03g	Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
VII	0.06g	Everybody runs outdoors. Damage negligible in building of good design and construction; slight to moderate in well-built ordinary structures, considerable in poorly-built or badly designed strctures; some chimneys broken. Noticed by persons driving motor cars.
VIII	0.14g	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly-built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned; Sand and mud ejected in small amounts. Changes in well water. Persons driving motor cars disturbed.
IX	0.3g	Damage considerable in specially designed structures; well designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

Table 1 (Contd.)

Intensity	Acceleration	Effects
X	0.6g	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.
XI	1.4g	Few, if any (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe pines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII	3g	Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

Table 2

	Energy Range ergs	Magnitude of mean
Great earthquakes	10^{26}	8.
Major earthquakes	$10^{24} - 10^{26}$	7.5
Destructive earthquakes	$10^{22} - 10^{24}$	6.5
Damaging earthquakes	$10^{20} - 10^{22}$	5.5
Minor strong earthquakes	$10^{18} - 10^{20}$	4.5
Generally felt small earthquakes	$10^{16} - 10^{18}$	3.0

For further discussion see Reference (3)

The earthquake damage scale given in Table 3 was used by the National Research Council in Reference (4). The accelerations given in the Table are those in a horizontal direction.

Table 3 - Earthquake Damage Scale

Grade A - Very violent (greater than 0.4 gravity).

Grade B - Violent (0.3-0.12 gravity).
Fissuring of asphalt; destruction of foundation walls and under-pinnings of structures; the breaking of sewers and water mains; displacement of street car tracks.

Grade C - Very strong (0.12-0.08 gravity)
Brick walls or masonry badly cracked with occasional collapse; frame buildings lurched or listed on fair or weak underpinning; general destruction of chimneys and masonry, cement or brick veneers; considerable cracking or crushing of foundation walls.

Table I

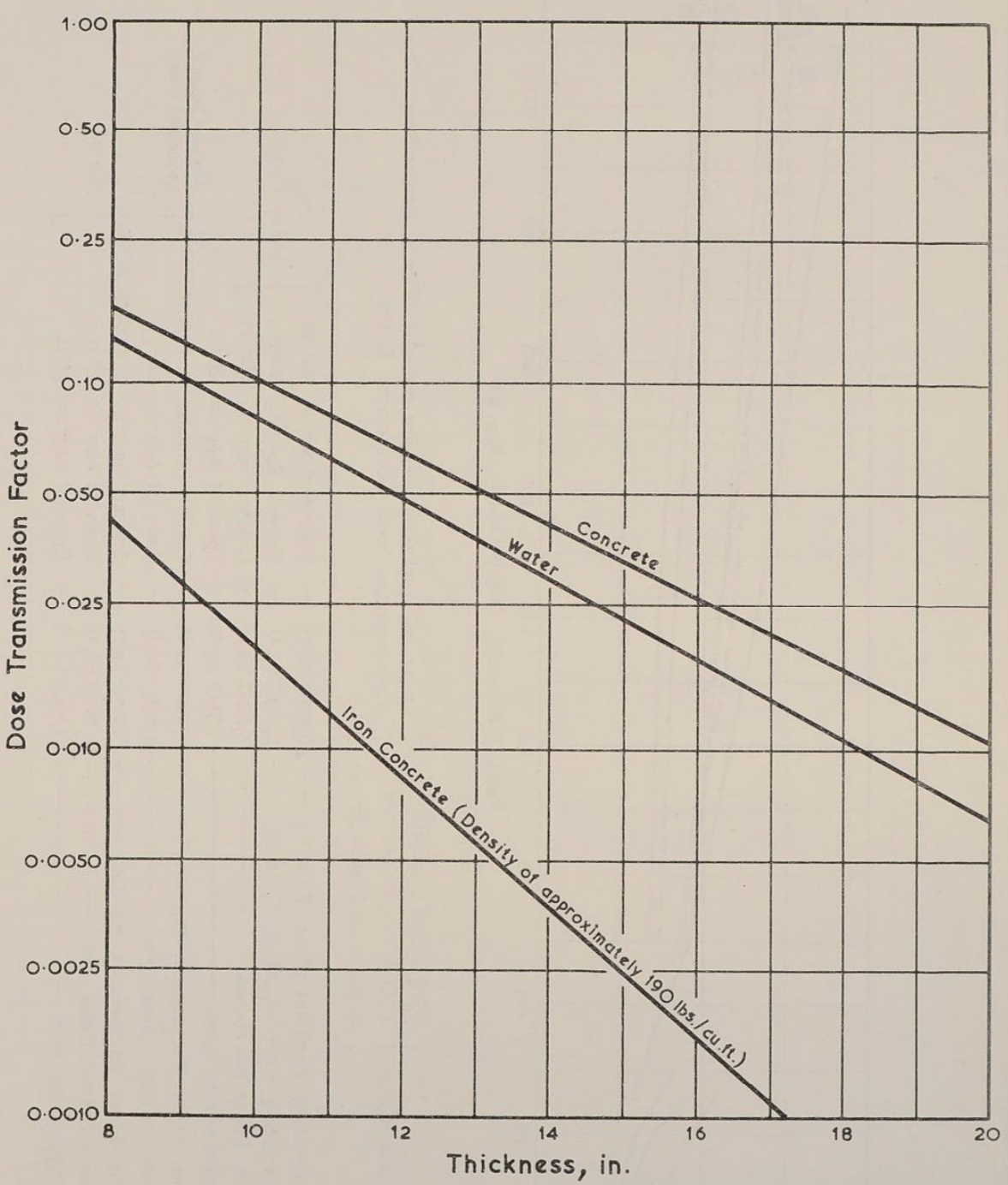
Item	Damage	Velocity (ft./sec.)	Remarks
Bridges	Severe	1.6	Bridge collapses
	Moderate	0.85	Bridge displaced
Airfield Runway Landing mat (steel)	Severe	1.1	Mat twisted and buckled
Airfield Runway* Landing strip (concrete)	Severe	2.0	Concrete cracked and displaced
	Moderate	1.5	Concrete will crack
	Light	1.0	Concrete slightly cracked
General Machinery (bolted down)	Severe	0.8	Gears and functional parts destroyed
	Moderate	0.6	Auxiliary equipment destroyed
	Light	0.5	Destroys alignment
Railway locomotives and rolling stock	Severe	1.1	Pushed over and twisted Probable fires
	Moderate	0.7	Derailment
Brick walls (12-18in.)	Severe	0.6	Collapse
	Moderate	0.5	Partial collapse and cracking
	Light	0.4	Cracking
Houses - brick	Severe	0.6	Collapse
	Moderate	0.5	Distortion and cracks
	Light	0.4	Plaster and window damage
Houses - wooden frame	Severe	0.8	Collapse
	Moderate	0.6	Distortion and cracks
	Light	0.45	Plaster and window damage
Multistory brick building	Severe	0.6	Collapse
	Moderate	0.5	Structural damage
	Light	0.4	Plaster and window damage
Reinforced concrete building	Severe	0.85	Collapse
	Moderate	0.7	Structural damage
	Light	0.6	Plaster and window damage
Steel, heavy frame building	Severe	0.7	Mass distortion
	Moderate	0.5	Structural damage
	Light	0.45	Plaster and window damage
Steel, light frame building	Severe	0.6	Mass distortion
	Moderate	0.5	Structural damage
	Light	0.4	Plaster and window damage
Underground pipes*	Severe	0.85	Pipes broken
Dams (cement)*	Severe	1.0	Cracked and displaced
Dams (earth)*	Severe	1.6	Cracked and displaced
Submarine pens*	Severe	1.6	Cracked and displaced
Railway lines*	Severe	1.6	Rails bent

*Note: There is experimental evidence to support this figure with these items.

C. Trials Reports

Ref. No.	U.K. Reference	U.S. Reference	Author	Title	Security Classn.
31	AWRE Report T 47/57		A.J. Wood	The Effect of Earth Covers on the Resistance of Trench Shelter Roofs	C
32	AWRE Report T 37/57		J.K. Wright	Operation Buffalos. Measurement of Ground Shock and Crater	Secret
33	AWRE Report T 42/58		A.G. Hunt	Operation Antler. Measurement of Ground Shock	C
34		WT - 727		Operation Upshot-Knothole. Air Blast Effects on Underground Structures	C
35		WT - 1127		Operation Teapot. Air Blast Effects on Underground Structures	C
36		WT - 1128		Operation Teapot. Evaluation of Earth Cover as Protection to Aboveground Structures	C
37		ITR-1404		Operation Plumbbob. Ground Acceleration, Stress, and Strain at High Incident Overpressures	C
38		ITR 1405		Operation Plumbbob. Ground Motion Studies at High Incident Overpressure	C
39	DGAW 565/60	WT - 1420		Operation Plumbbob. Blast Loading and Response of Concrete-Arch Protective Structures	C
40		WT-1424		Operation Plumbbob. Isolation of Structures from Ground Shock.	
41		WT-1425		Operation Plumbbob. Full-scale Field Tests of Dome and Arch Structures	
42		ITR-1447		Operation Plumbbob. The Internal Environment of Underground Structures subjected to Nuclear Blast. I - The occurrence of dust	O.U.O.
43	DGAW 67/59	ITR-1448		Operation Plumbbob. Field Test of Reinforced Concrete Dome Shelters and Prototype Door	O.U.O.
44		ITR-1449		Operation Plumbbob. Response of Dual-purpose Reinforced Concrete Mass Shelter	O.U.O.
45		ITR-1459		Operation Plumbbob. Evaluation of Industrial Doors Subjected to Blast Loading	O.U.O.
46		ITR-1460		Operation Plumbbob. Test and Evaluation of Anti-Blast Valves for Protecting Ventilation Systems	O.U.O.
47		ITR-1475		Operation Plumbbob. Blast Effects on Air-Cleaning System	O.U.O.
48	DGAW 296/60	ITR-1613		Operation Hardtack. Ground Motion Produced by Nuclear Detonations	Secret Atomic
49		ITR-1631		Operation Hardtack. Damage to Existing EPG Structures	Secret
50	Home Office C. 12398	ITR-1703		Operation Hardtack. Surface and Sub-surface Strong Motion Measurements	U
51		ITR-1714		Operation Hardtack. Evaluation of Blast and Shock Effects on Tunnel Support Structures.	U

PART IV
CHAPTER 6
FIGURE 3

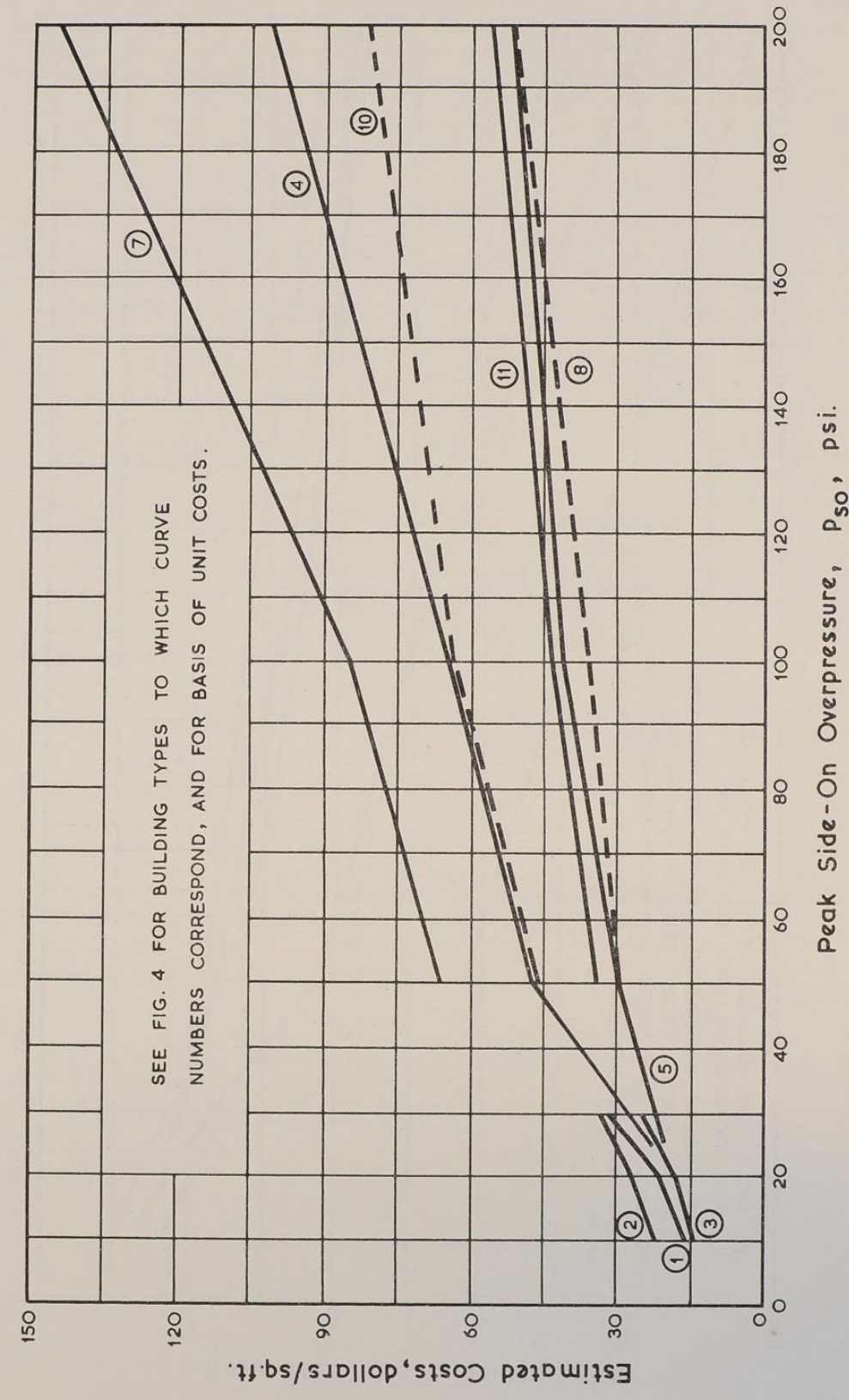


ATTENUATION OF FAST NEUTRON RADIATION — BROAD BEAM IN THICK SHIELDS.

PART IV
CHAPTER 6
FIGURE 4

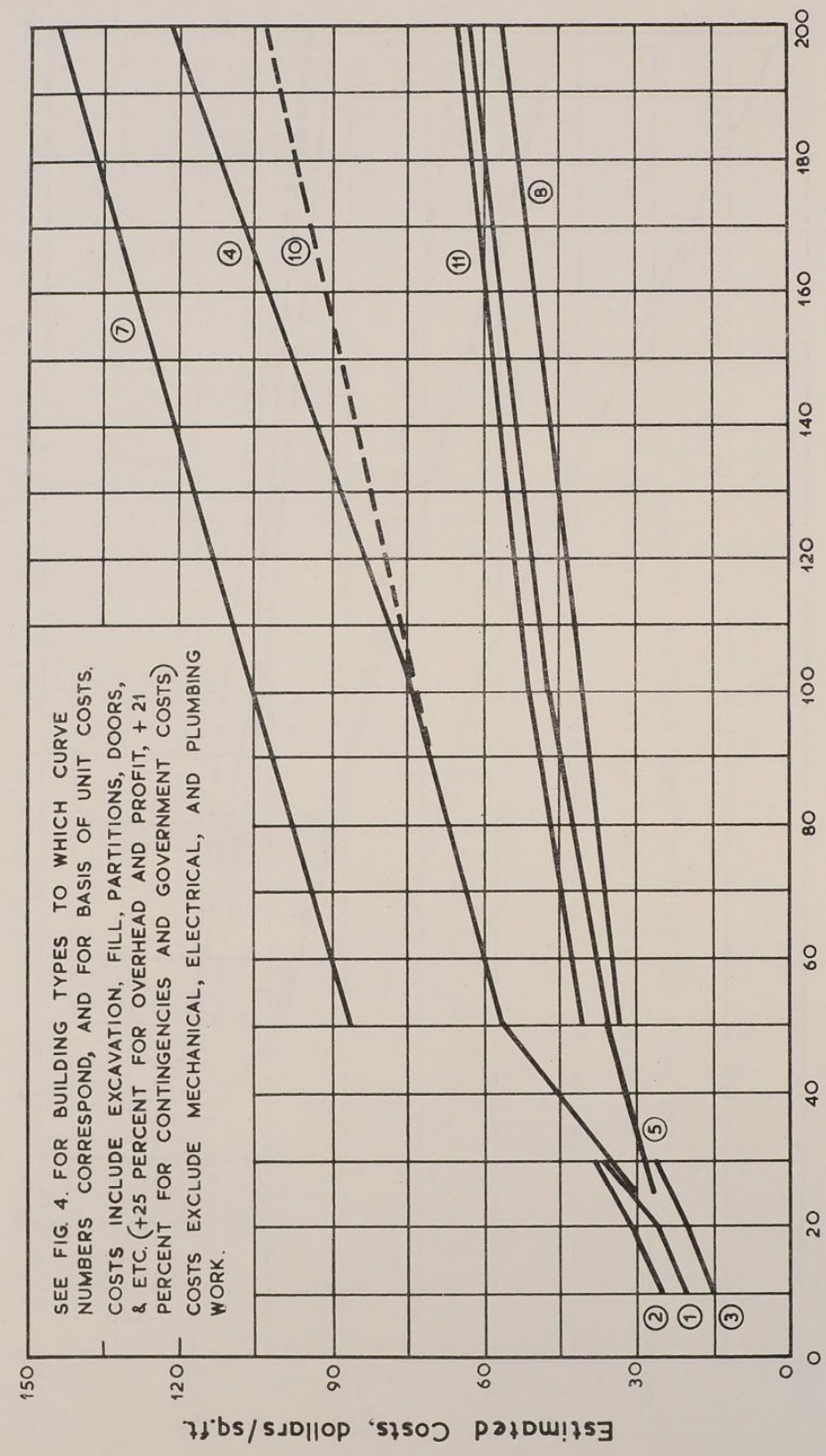
ESTIMATED COST OF BARE STRUCTURE, EXCLUDING ENTRANCE STRUCTURES

PART IV
CHAPTER 6
FIGURE 5



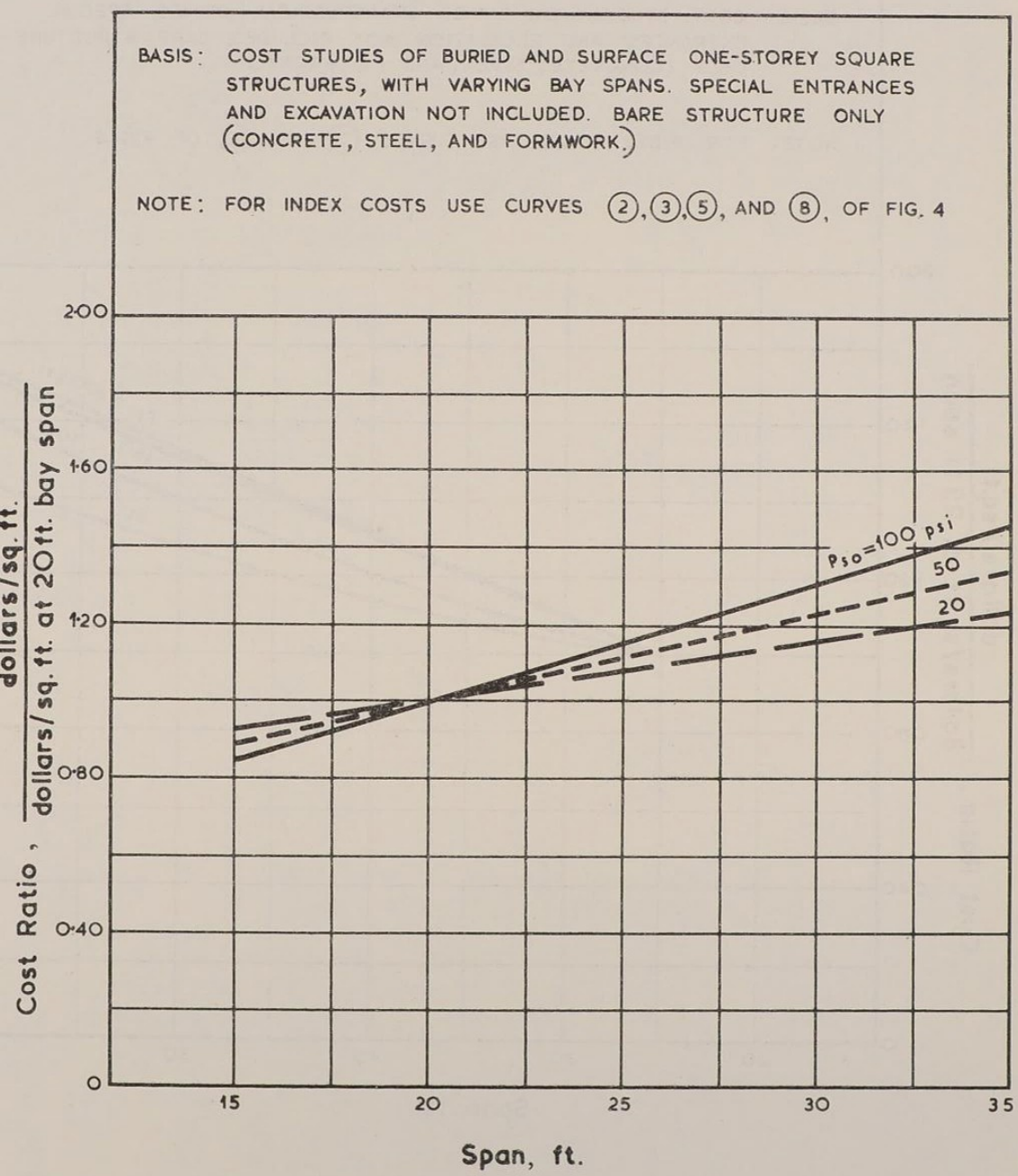
ESTIMATED COST OF BARE STRUCTURE, INCLUDING SPECIAL ENTRANCE STRUCTURES.

PART IV
CHAPTER 6
FIGURE 6

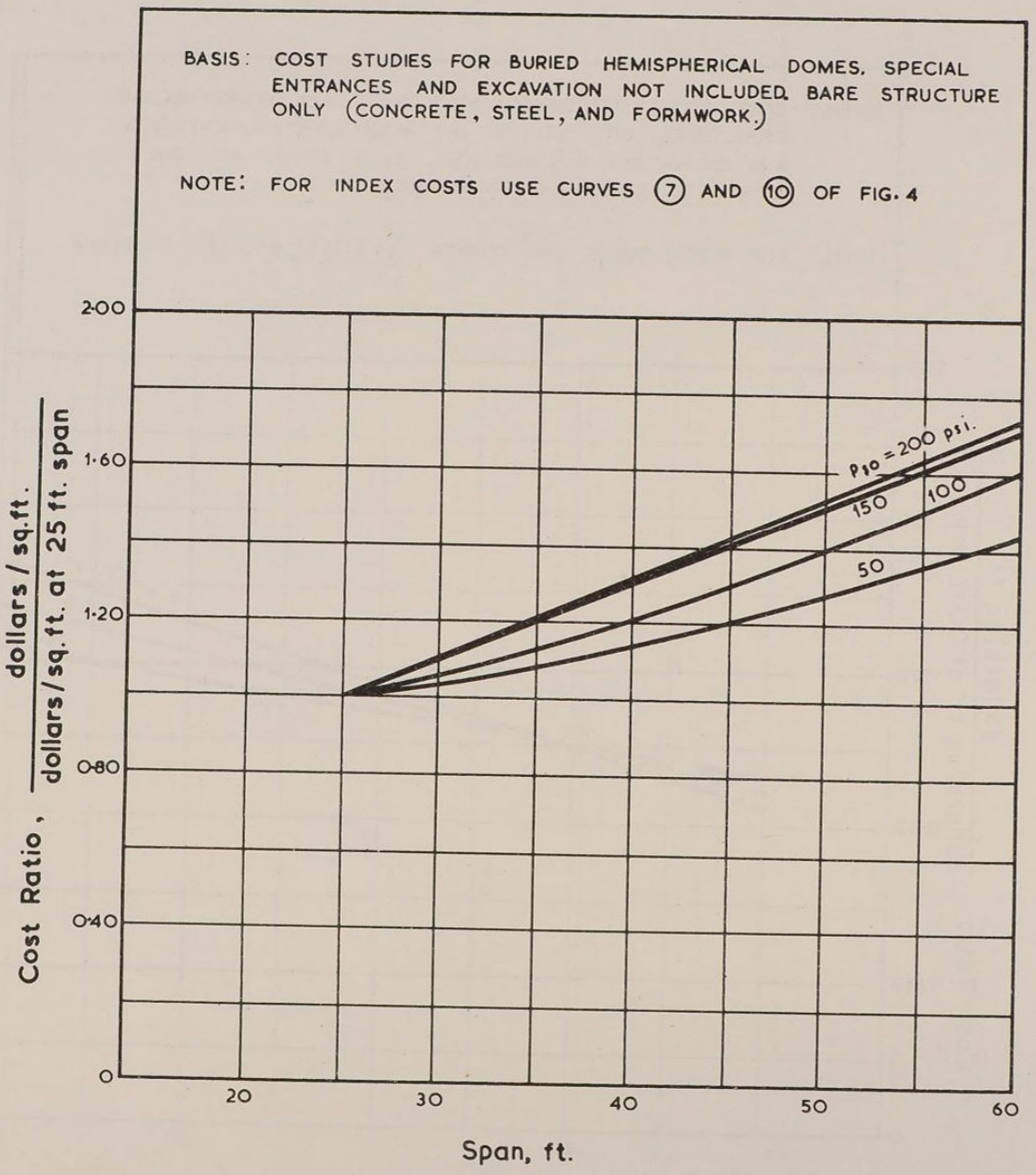


ESTIMATED COST OF STRUCTURES

PART IV
CHAPTER 6
FIGURE 7

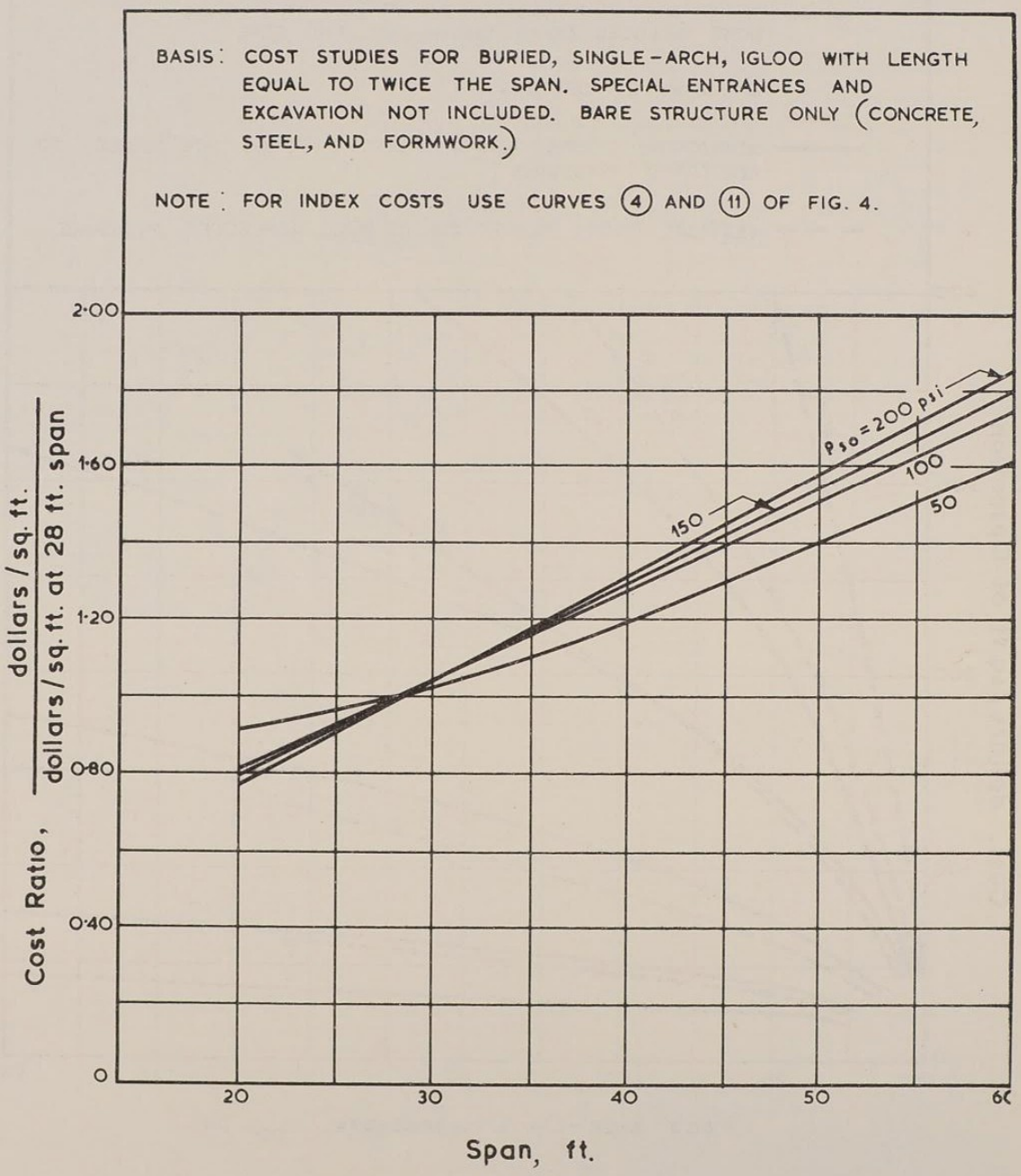


COST RATIO VERSUS SPAN FOR ONE-STOREY RECTANGULAR STRUCTURES



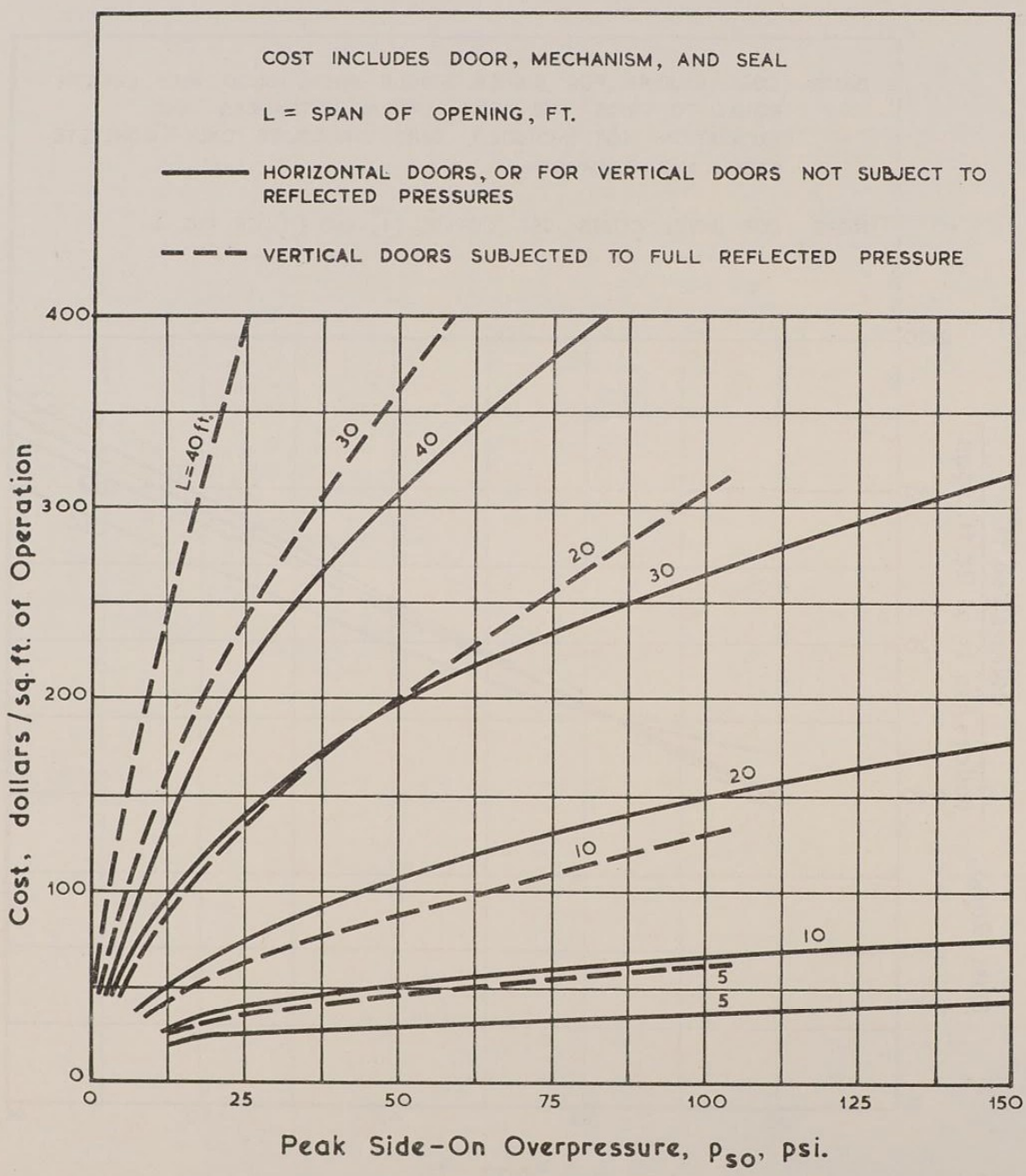
COST RATIO VERSUS SPAN FOR DOME STRUCTURES.

PART IV
CHAPTER 6
FIGURE 9



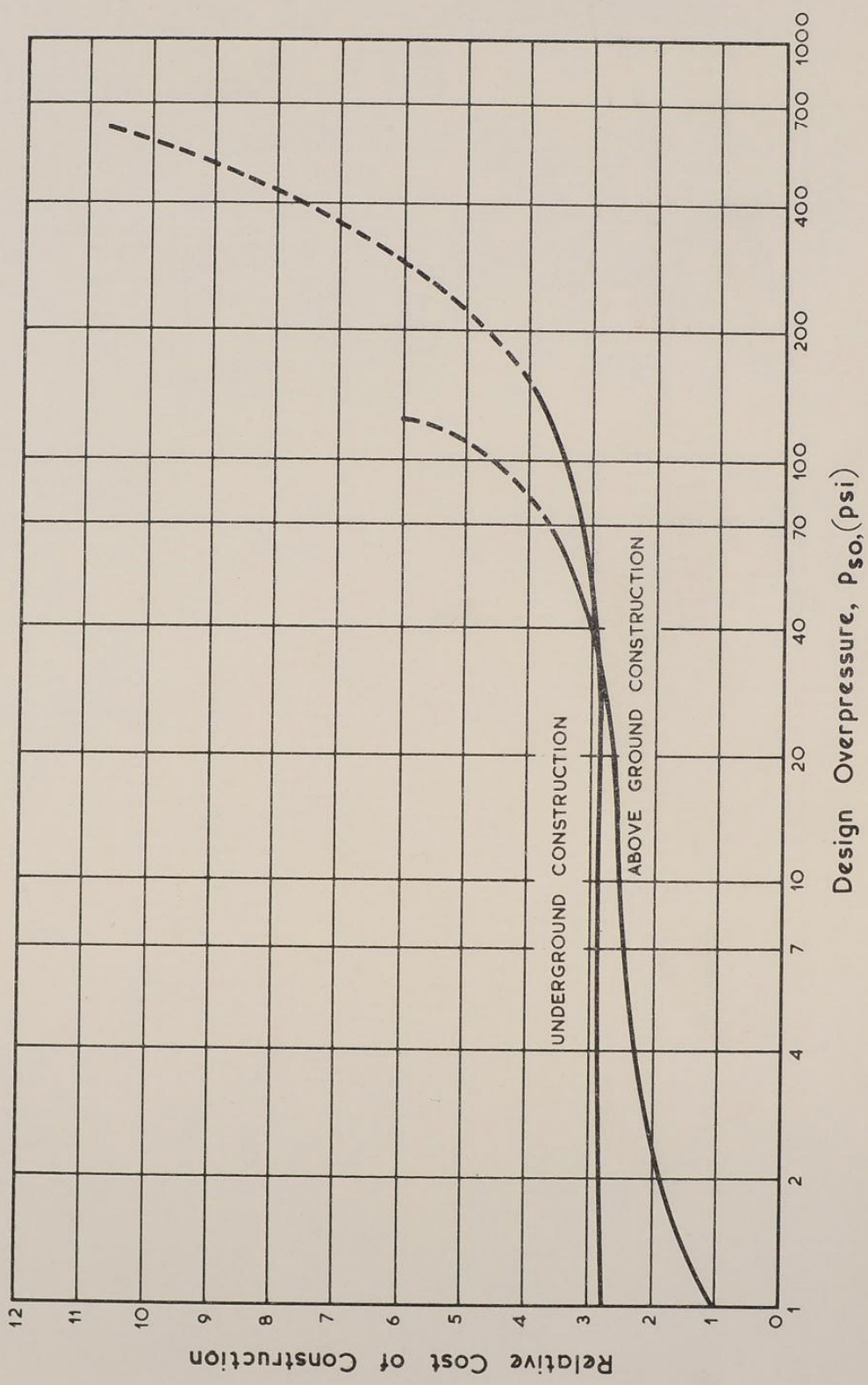
COST RATIO VERSUS SPAN FOR ARCH (IGLOO) STRUCTURES.

PART IV
CHAPTER 6
FIGURE 10

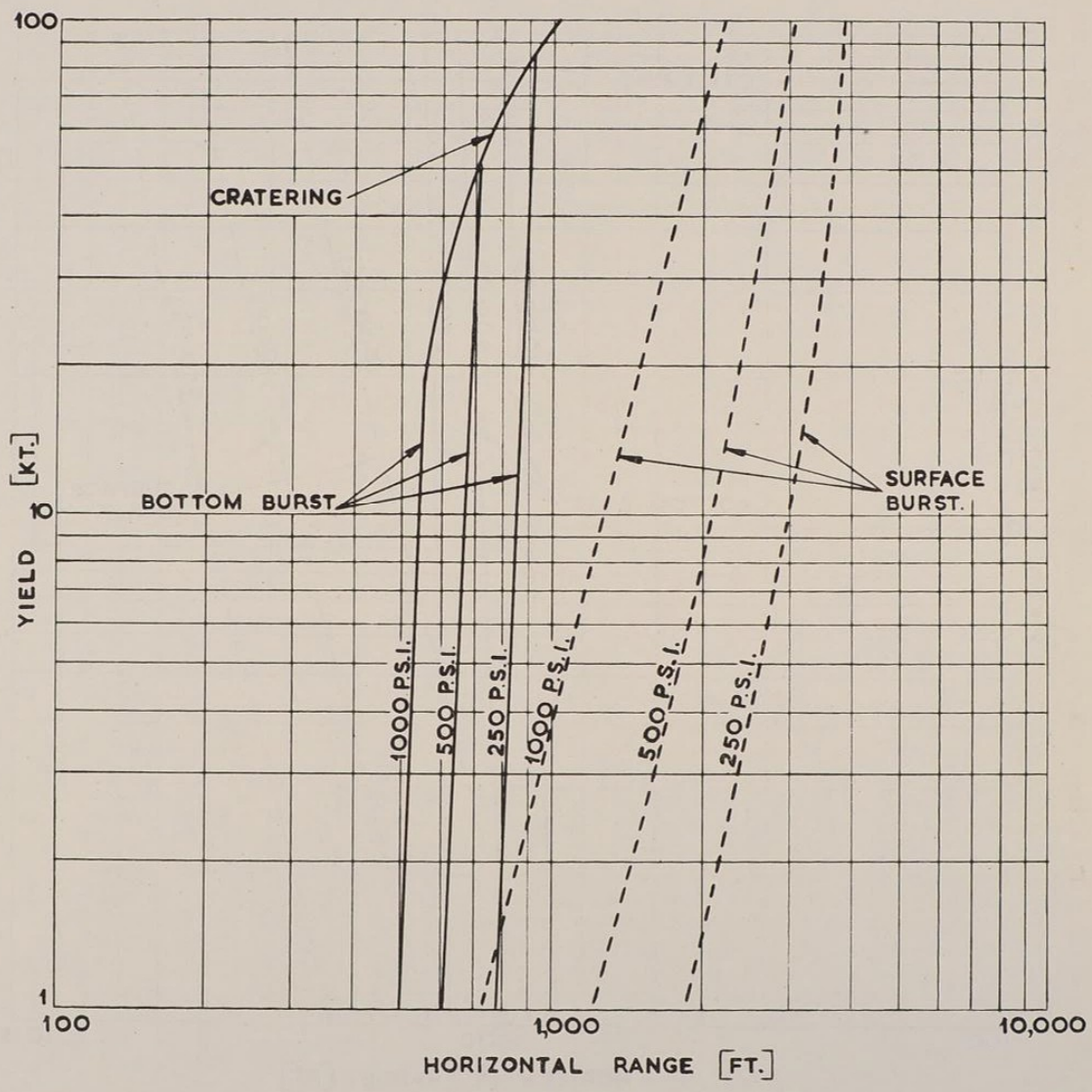


COST OF PROTECTIVE DOORS

PART IV
CHAPTER 6
FIGURE 11



RELATIVE COST OF CONSTRUCTION VS DESIGN OVERPRESSURE



UNDERWATER MINEFIELD NEUTRALISATION,
50FT. DEPTH OF WATER, MINES ON BOTTOM

PART V
CHAPTER 5
SECTION 5.2
FIGURE 2

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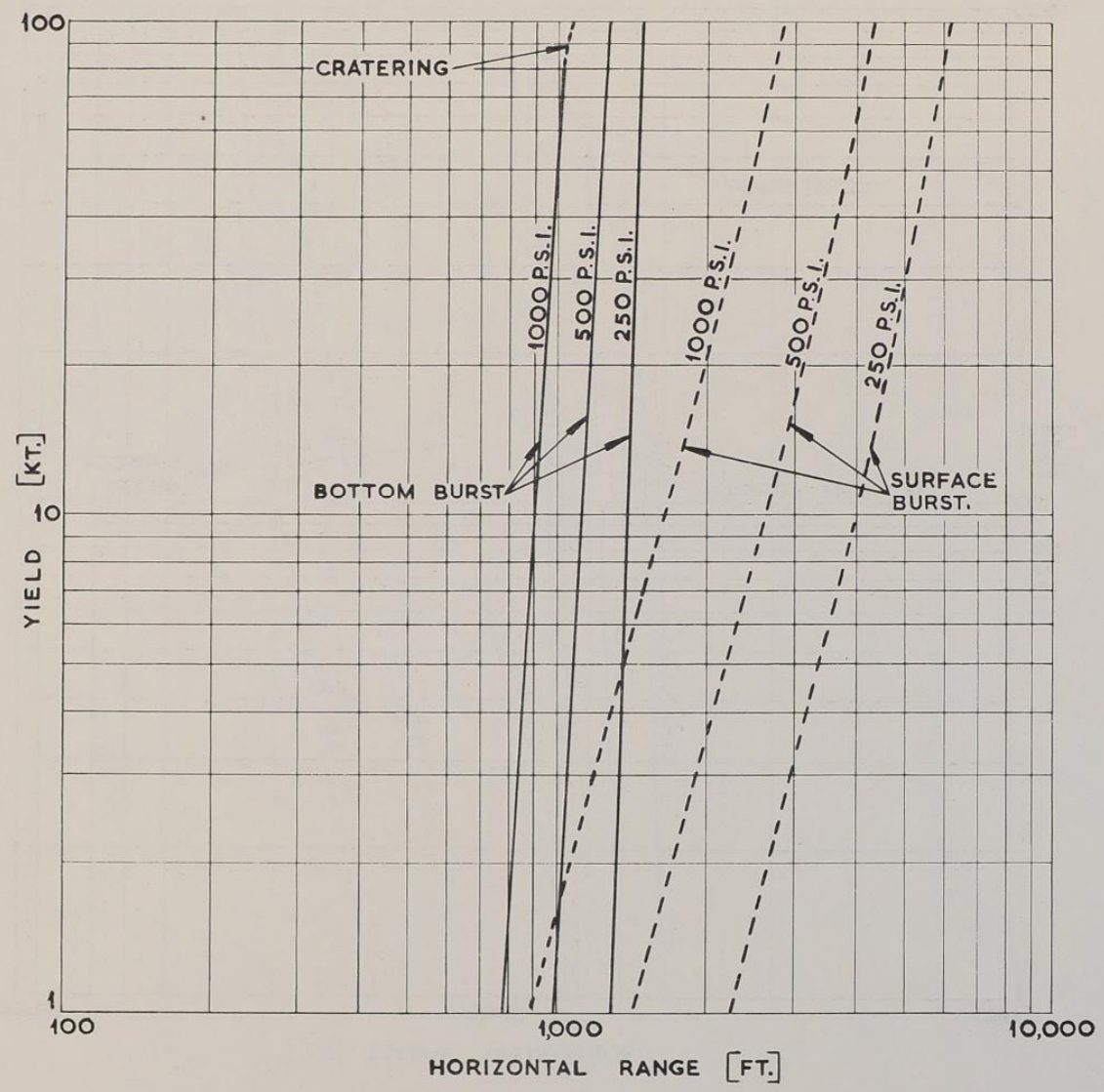
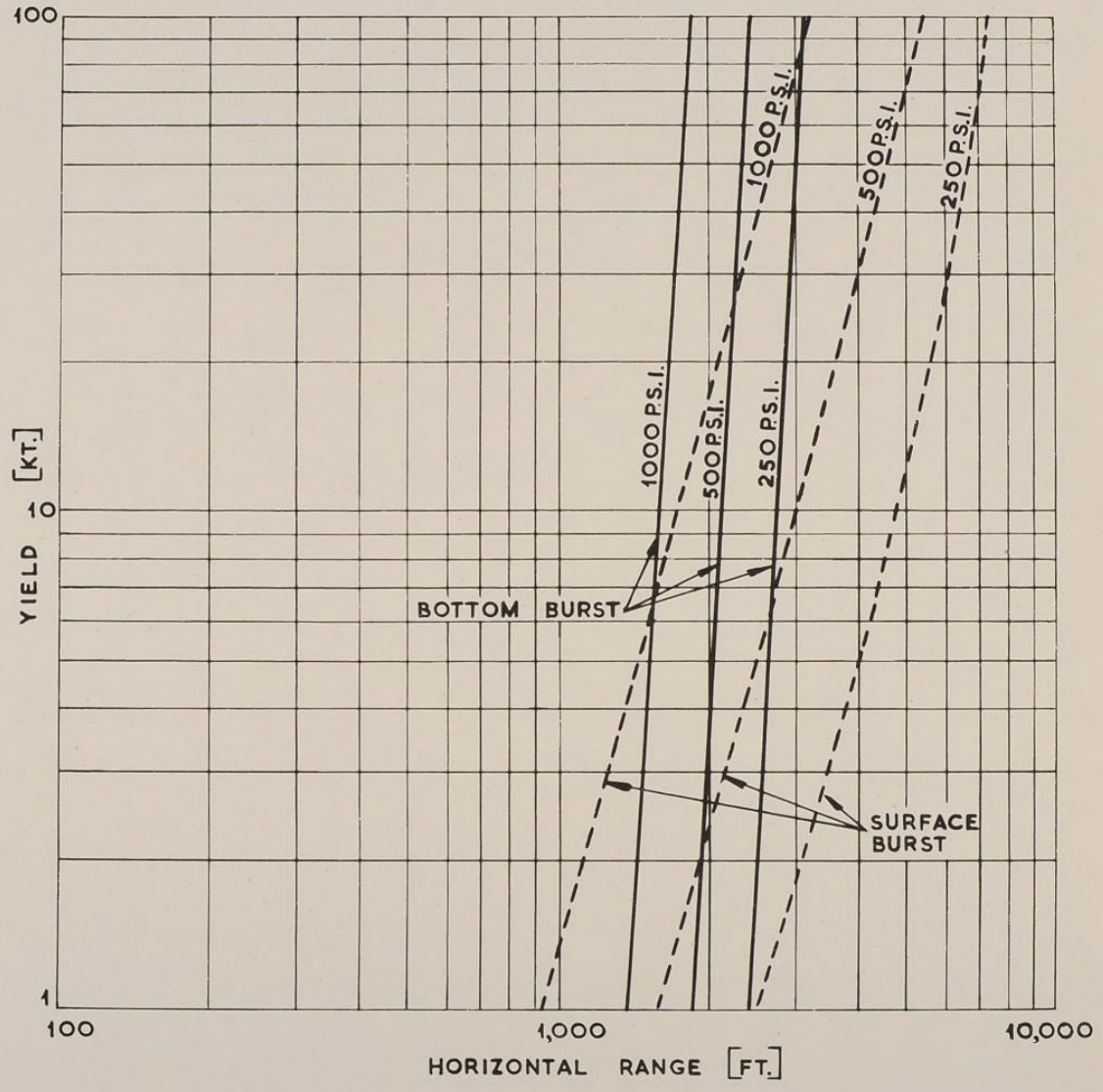


UNDERWATER MINEFIELD NEUTRALISATION,
100FT. DEPTH OF WATER, MINES ON BOTTOM

UNCLASSIFIED

PART V
CHAPTER 5
SECTION 5.2
FIGURE 3



UNDERWATER MINEFIELD NEUTRALISATION,
200 FT. DEPTH OF WATER, MINES ON BOTTOM

5.3 Underwater Pipe Lines

Pipe lines that are completely filled with liquid are unlikely to be damaged unless within the crater. Gas filled pipe lines will be destroyed when the peak shock pressure exceeds the static collapse pressure by a small margin and the curves of figures 1, 2, 3 of Section 5.2 are applicable.

Pipes which are only partially filled with fluid will be collapsed on to the fluid at the destruction range for gas filled pipe lines. This may or may not lead to rupture depending on the proportion of liquid filled volume, ductility etc.

5.4 Dock Gates

The vulnerability of Dock Gates to underwater attack can be expected to be very sensitive to the height of water on both sides of the gate and to the type of gate. A gate of solid construction with the water level on the attacked side no higher than on the other side will be very little affected by the underwater shock at ranges where the surface waves would probably cause serious damage. For the same gate with the water level on the attacked side say 20 ft. higher than on the other side, the underwater shock can be expected to be the most important damaging agent unless the surface waves are increased by focussing, shelving bottom etc. In the latter case neglecting wave actions, the energy parameter E_H (Section 3.4) should give a fairly reliable damaging criterion with a value $E_H = 5.10^4$ ft./lb./ft.^{2} leading to rupture.

Dock Gates of watertight "egg box" construction can be expected to behave as ships' sides regardless of the relative heights of the water on the two sides. Damage leading to rupture could be expected on the attacked side when $E_H = 5.10^4$ ft.lb./ft.^{2} and this may or may not affect the operation of the gate depending upon the detail design. The side not attacked, if water backed, could be expected to be difficult to rupture, but the gate would probably be inoperable, although possibly still fairly watertight, long before rupturing stand-off is reached.

5.5 Dams

Concrete dams are likely to be more vulnerable to underwater shock than to airblast when the water level is higher than about half dam height. As the depth of water increases the vulnerability of the dam to an underwater burst increases. This is partly due to the increased static loading but is mainly due to the increased pressure pulse durations with deeper water. The great mass of dams makes it likely that damage will be governed by impulses rather than energy. This is assumed in Reference (1) where the following damage estimates are given for full concrete gravity dams (straight or slightly curved in plan) for a 20 K.T. underwater burst.

60 ft. high dam

Cracks are produced at a range of about 300 yds. Portions are cracked loose and displaced small distances at a range of about 200 yds.

150 ft. high dam

Cracks are produced at a range of about 500 yds. Portions are cracked loose and displaced sizeable distances at a range of about 200 yds.

500 ft. high dam

Cracks are produced at a range of about 1,300 yds. Portions are cracked loose and displaced large distances at a range of about 200 yds.

These estimates for cracking correspond to impulse values at the mean height facing the charge of 2.4, 4.7 and 6.5 p.s.i. seconds for 60, 150 and 500 ft. high dams respectively.

The cracking loose estimates correspond to impulse values at the same position of approximately 5.7, 32, 170 p.s.i. seconds for 60, 1,500 and 500 ft. high dam respectively.

5.6 Wave Damage

The question of wave damage to dock gates or indeed to any harbour installation requires an individual analysis of each target. The variables involved are water depth, bottom slope, wave height, wave length, target response characteristics, orientation of target to wave front, location of target relative to the point of wave breaking and variation in width of the channel or harbour.

The estimation of water height in water of uniform depth is treated in Data Sheet 4.11 of the Manual on the Effects of Atomic Weapons. Further curves of estimated wave heights reproduced from "Capabilities" are given in figure 1. These latter curves do not entirely agree with the data given in M.E.A.W. and the disagreement reflects the degree of ignorance on this problem.

An example of the types of problem that arise is given by considering the effect of a 20 K.T. underwater explosion in the Bristol Channel. Provided this is carried out at least 20 miles from land in a favourable wind the problems arising from airblast, thermal, gamma radiation or underwater shock would be minor. The wave height reaching the Gower Peninsula and the Devon Coast would be around 2 ft. but the progress of this wave down the Bristol Channel could lead to a magnification of the wave height. The wave height in a slowly narrowing channel is inversely proportional to $(\text{breadth})^{\frac{1}{2}} \times (\text{depth})^{\frac{1}{4}}$, thus the wave height may reach about 30 ft. at Avonmouth and even higher further down the Severn.

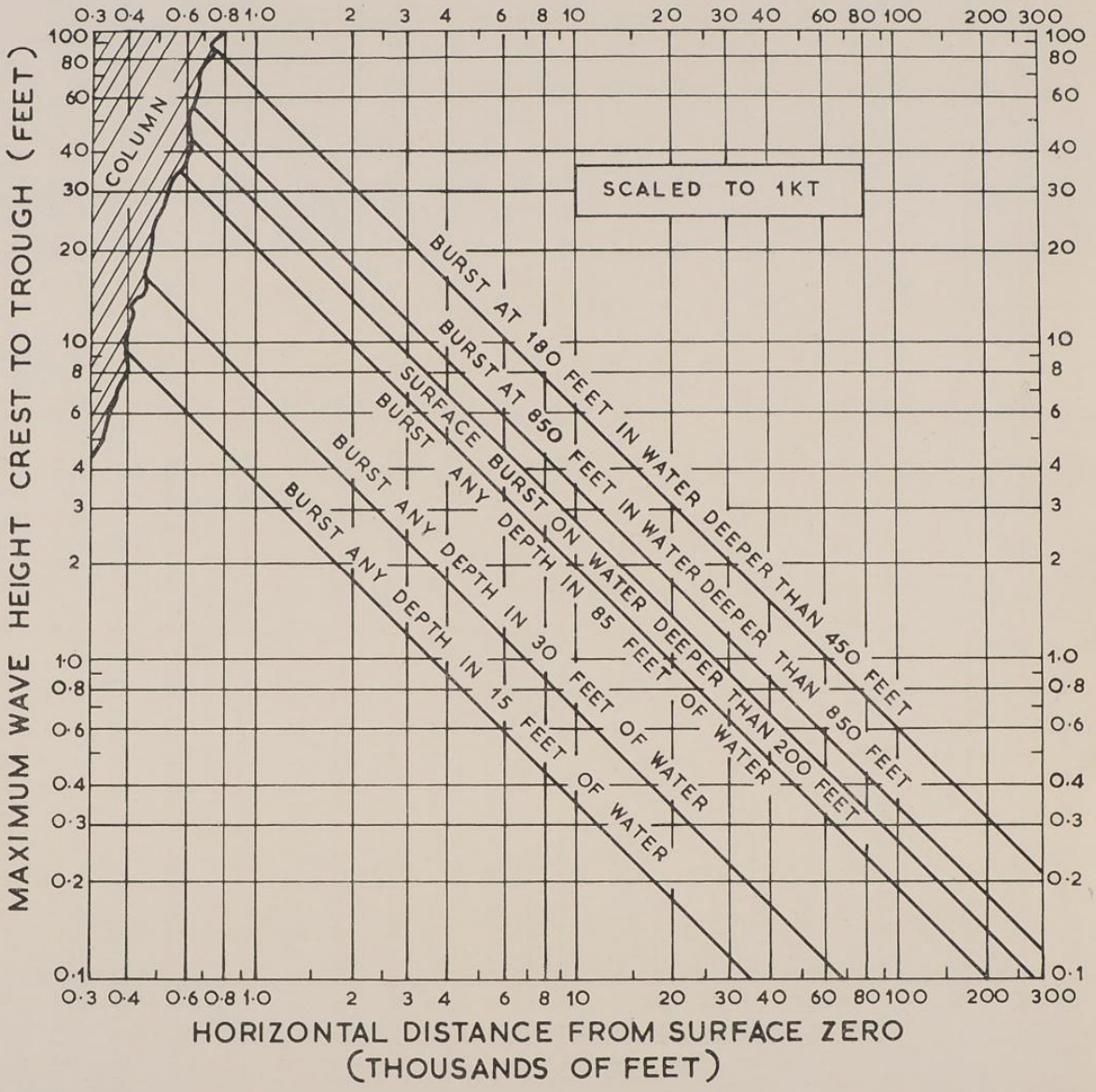
This type of consideration may be a limiting factor in the use of atomic depth charges around coasts, and requires study.

Reference

1. Capabilities of Atomic Weapons. T.M.23 - 200 Revised Edition 1st June, 1955, Fig. 51, and November, 1957 Edition Fig. 2-34. (CONFIDENTIAL).

CONFIDENTIAL

PART V
CHAPTER 5
SECTION 5.6
FIGURE 1



ESTIMATED WAVE HEIGHTS FOR WATER BURSTS

CONFIDENTIAL

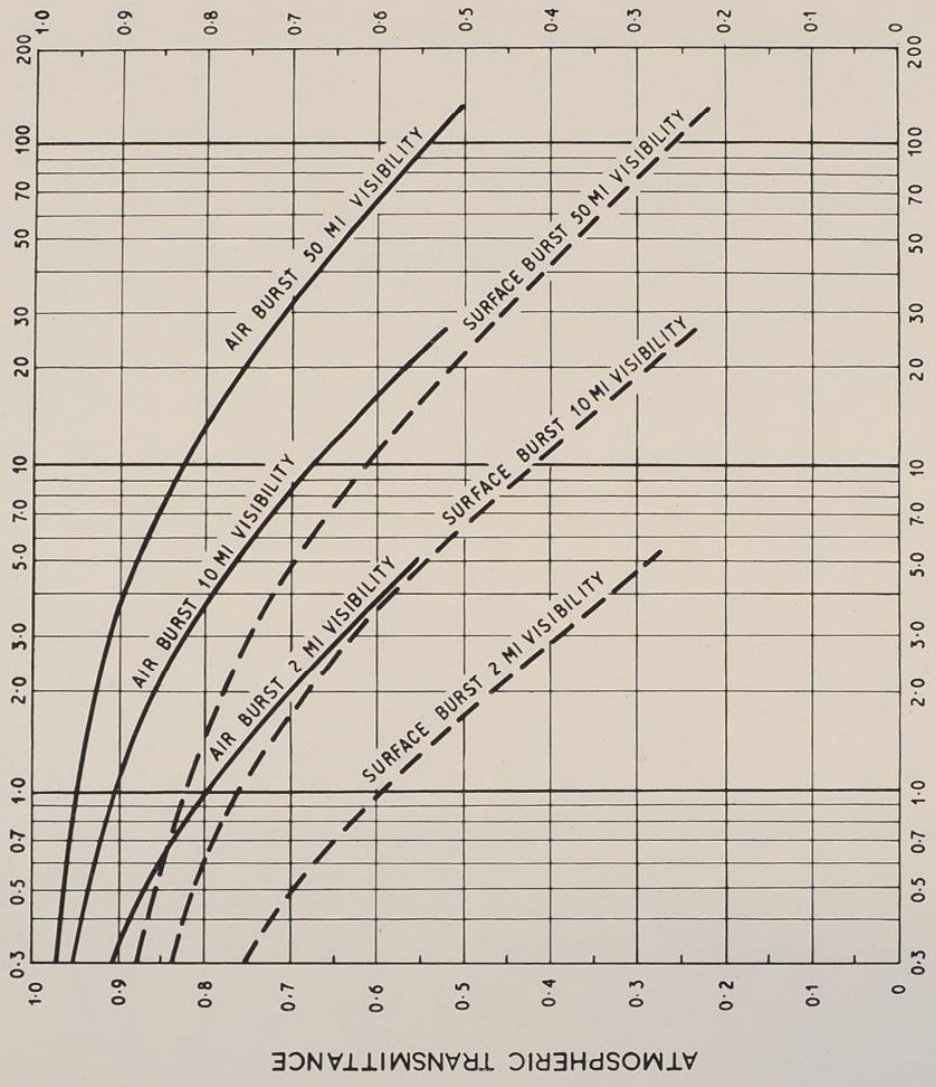
In underground bursts the fireball is obscured by the earth column, and therefore thermal radiation effects are negligible. Nearly all of the thermal radiation is absorbed in fusing and vaporizing the earth.

Thermal radiation from an underwater detonation is increasingly absorbed in vaporization and dissociation of the surrounding medium as the depth of burst is increased. Its direct effects are insignificant for most practical purposes; e.g. for a 20-KT burst ninety feet below the surface of water, thermal effects are negligible. (Reference (2)).

References

(1) Effects of Nuclear Weapons, U.S.A.E.C. (1957) p.19.

(2) Capabilities of Atomic Weapons, U.S. Dept. of the Army, TM 23-200 (1957) p.3 - 1. (Confidential)



ATMOSPHERIC TRANSMITTANCE AS A FUNCTION OF SLANT RANGE FOR AIR AND SURFACE BURSTS

1.3.3. Calculation of the energy absorbed

The thermal energy absorbed per unit area of a surface will depend upon:-

(i) The absorptivity, reflectivity and emissivity of the surface. The reflectivity (r) of a surface is equal to (1 - a), where (a) is the absorptivity, or to (100 - a) if both are expressed as percentages. The emissivity $\bar{e}$ for radiation of any particular wavelength is equal to a for the same wavelength. For a perfect black body, or a perfect grey body, a and $\bar{e}$ are equal and constant over the whole waveband. Practical surfaces are, however, selective absorbers, and there is no relation between the degree of absorption of radiation from a 6000°K source and the efficiency of emission of radiation characteristic of a temperature of 200°C to 300°C. Thus, many white surfaces, including white paints, are poor absorbers of high temperature radiation and good emitters of low temperature radiation.

(ii) The angle of incidence of the radiation. By simple geometry, if radiation of intensity Q cals/cm^2 falls onto a surface at an angle α to the normal, then the effective radiation intensity Q_α is given by:-

$$Q_\alpha = Q. \cos \alpha \text{ cals/cm}^2.$$

For most practical surfaces the absorptivity is independent of the angle of incidence, except for large angles (grazing incidence) at which the absorptivity decreases. If however, the surface has a marked structure, absorption may vary considerably as the angle of incidence increases. Such an effect may be produced by unusual surface topography, or by anisotropy in the structure of the surface. The effect must be determined for each type of surface. Uniform absorptivity should be assumed and the simple geometrical law used unless there is reason to suppose otherwise.

A further, and more detailed discussion of thermal energy absorption is given in Chapter 3, which deals with the temperature rise of irradiated materials.

D1/57
November, 1958

CHAPTER 2 - SHADOWING AND SHIELDING

2.1. Introduction

Thermal radiation from a nuclear weapon will not be received uni-directionally, for two reasons; firstly, because of the extended size of the fireball, and secondly, because of the contribution of scattered radiation.

The effect of scattered radiation becomes significant in the estimation of doses from air burst megaton weapons at long ranges. The visible and ultra-violet part of the radiation is scattered rather than absorbed by air and will not therefore, be greatly attenuated, but will move outwards after multiple scattering. Apart from the losses by infra-red absorption, the outward flux in any element of solid angle will therefore be constant and the intensity will decay only with the inverse square law of distance. The mean free path of the photon of visible light (i.e. the average distance it travels before being scattered, or the reciprocal of the attenuation coefficient) will be of the order of 600-10,000 yards, according to visibility. At ranges of not more than one mean free-path length, the radiation will be sensibly radial, i.e. sharp shadows will be formed. At ranges of several free-path lengths the total radiation will be little attenuated except for infra-red absorption, but the outward flux will be progressively more diffuse. In any element of solid angle therefore, the radiation passing through a given cross section will be constant, but will be distributed in the form of a polar diagram. At ranges equivalent to hundreds of free-path lengths this diagram would tend to be spherical, i.e. the illumination would be nearly non-directional, but at such lengths the dose would be insignificant.

2.2. Diffuse Atmospheric Transmission. Windows.

For an accurate assessment of the amount of thermal radiation falling on a surface inclined at an angle to the source or upon a surface receiving radiation from a limited field of view (e.g. through a window) it is necessary to know the polar distribution of the radiation on arrival.

Some limited experimental work suggests that the peak intensity of the thermal radiation reaching a surface from a field of view β radians diameter directed towards the source, is given by:-

$$\overline{T}_\beta = \overline{T} + g\,(1 - \overline{T})\,(1 - e^{-\beta})$$

where $\overline{T}$ is the specular transmittance

$\overline{T}_\beta$ is the apparent transmittence for the field of view β.

$\overline{T} = e^{-\mu D}$ where μ is the mean attenuation coefficient for all wavelengths in the fireball spectrum and D is the distance of the receiving surface from the point of burst.

In the formula above $(1 - \overline{T})$ represents the amount of scattered radiation. g is a constant varying between $\frac{1}{2}$ and 1 representing the loss of scattered light to the ground. $(1 - e^{-\beta})$ is an empirical correction, determined by experiment, for the fraction of the scattered radiation coming from the field of view β. Extended experiments in the U.K. seem to suggest that doses estimated in this way will in general overestimate the diffuse dose.

A more detailed treatment of the above formula is given in M.E.A.W. Data Sheet 3.5A and M.E.A.W. Fig. 3.5.2 shows $T\beta$ as a function of $\overline{T}$ for various values of β and g.

Detailed mathematical treatments of the radiation scattering problem have been attempted in References (1) and (2).

A less sophisticated method of attack is to assume the radiation reaches the surface in three ways:-

(a) By direct specular transmission.

(b) By two rectilinear (attenuated paths) with one single scattering between them.

(c) The residual scattered radiation is then assumed to be isotropically diffuse and to reach the source uniformly from all directions.

Calculations based on this method of analysis are likely to be adequately accurate for many purposes. Some experimental and theoretical results are discussed in Reference (3).

References

(1) Sliepcevich, C.W. et alia. Attenuation of Thermal Radiation by a Dispersion of Oil Particles. Parts I and II. University of Michigan, 1954. (Unclassified).

(2) Smith, M.G. The Six Flux Method as an Approximation to the Transport Equation. A.R.D.E. Memorandum (B) 23/58. (Restricted/Discreet).

(3) Dorman, R.G. and Wootten, N.W. Atmospheric Attenuation of Radiation. C.D.E.E. Porton Technical Paper (R) 14. (Restricted).

Area smoke screens were used in World War II to protect important targets from observation, and there is considerable operational experience available from the use of these screens. However, since the opacity requirement and conditions of irradiation are different in the two cases, it is not possible at present to scale up the effect and quantities required and to give a full evaluation.

In the U.S., the use of fog oil smoke has been investigated both in the laboratory and in the field, and has been given a full-scale test in an atomic explosion. It was concluded that 200-400 gallons of fog oil per square mile of screen would reduce the thermal radiation from 10-100 KT weapons detonated at optimum height, to 3 cals/cm^2 or less at points immediately outside the 6-8 p.s.i. blast contour. Further details are given in Reference (2). A theoretical treatment of this problem is given in References (3) and (4).

Thermal attenuation by fog oil smoke is essentially by scattering alone. According to Reference (5), a material which included absorbing properties as well, such as carbon smoke, is likely to prove more economical. The weight of material in suspension could thereby be reduced, probably by a factor of a half or a third.

Reference (6) gives an account of field trials made to assess the attenuation of solar radiation by zinc hexachloroethane (HCE), which is a partial absorber owing to the presence of carbon in the smoke. From the results obtained an estimate is made of the effectiveness of HCE area smoke screens in attenuating thermal radiation from nuclear explosions.

The practical utility of smoke screens, assuming that the quantities and effort required are acceptable, turns very largely upon the frequency of occurrence of suitable weather conditions. It has been estimated that over U.S. cities meteorological conditions are favourable to the formation of smoke screens for 90-95% of the time if area sources of smoke are used, and 40-80% if line sources are employed, (Reference (2)).

References

(1) Staff Officers' Manual - Atomic Weapons Employment, U.S. Dept. of the Army, FM 101-31A p.10. (Secret Atomic)

(2) Engquist, E.H. CRLR.466. "Interim Comprehensive Report on Thermal Radiation Attenuation by Oil - Fog Smoke Screens". U.S. Chemical Corps. 23.3.55.

(3) Chu, C.M., and Churchill, S.W. J.Phys.Chem., 1955, Vol. 59, p.855.

(4) Sliepcevich, C.W. "Attenuation of Thermal Radiation by a Dispersion of Oil Particles", Parts I and II. University of Michigan, 1954.

(5) Ford, J.J. CRLR.252. "Thermal Attenuation Effects of Black Smoke". U.S. Chemical Corps, 10.9.53.

(6) Sawyer, K.F., and Wootten, N.W. "Field Trials on the Attenuation of Solar Radiation by Smoke Screens". Porton Technical Paper (R)1. August, 1956. (Confidential/Discreet)

2.4. Effectiveness of Shielding

Apart from the effects of scattering the thermal radiation from a nuclear explosion travels in straight lines from the fireball. Any solid opaque material such as a wall, a hill, or a tree between a given target and the fireball may act as a shield and provide protection from thermal radiation. Instances of such shielding observed after a nuclear explosion in Japan are given in Reference (1).

A shield which merely intervenes between a given target and the ball of fire, but does not surround the target, may not be entirely effective under hazy atmospheric conditions. A large proportion of the thermal radiation received, especially at considerable distances from the explosion, has undergone scattering (see Sections 2.1, 2.2, and 2.3) and will arrive from all directions, not merely that from the point of burst. It should also be borne in mind that at close ranges, where the fireball subtends a relatively large angle, the shadowing effects of intervening objects are less than are experienced with the sun.

An assessment of the value to troops of slit trenches, as protection against thermal and gamma radiations from nuclear explosions, is given in Reference (2). It is concluded that open slit trenches afford considerable overall protection to personnel against thermal and gamma effects of nuclear weapons. Even when least effective (i.e. against high air bursts), they may be expected to save about 40% of the total casualties (from nuclear and thermal radiation) which would result from all men being in the open. This figure increases with decreasing burst height, up to a maximum of about 97% for low air bursts. Trenches with thermal screens afford much greater protection than open trenches against high air bursts, but about the same protection against low air bursts.

In a report on the vulnerability of Armoured Fighting Vehicles and their crews to nuclear weapons (Reference (3)), an assessment is made of the protection afforded against thermal radiation. It is concluded that closed-down vehicles give good protection against thermal radiation, but that there is a possibility of burns being caused by the transmission of radiation through optical instruments.

Transparent materials such as glass and plastics allow thermal radiation to pass through only slightly attenuated. Methods of treating window-glass to provide heat radiation shields are described in Reference (4). These methods consist in applying a coating to the window which reduces the radiation transmitted and scatters the part which is transmitted. Thus not only is the total quantity of heat entering the room reduced, but its intensity is more evenly distributed. The best coatings for this purpose are white, and those that last longest are of the high gloss or cement paint type; emulsion paints are ineffective. The protection is reduced if the windows are blown out by the blast wave before all the thermal energy is delivered.

References

(1) Effects of Nuclear Weapons. U.S.A.E.C., 1957, pages 312-316.

(2) A.O.R.G. Report No. 12/55 "The Protective Value to Personnel of Slit Trenches against Thermal and Gamma Radiation Effects of Nuclear Explosions. (Secret/U.K. Eyes Only)

(3) A.O.R.G. Report No. 4/58 - "The Vulnerability of Armoured Fighting Vehicles and Their Crews to Nuclear Weapons". (Secret/Discreet)

(4) Joint Fire Research Organisation S.R. Note 28/1956 "Heat Radiation Shields for Defence against Atomic Explosions". Simms D.L., Hinkley, P.L., and Weston, M.A. (Confidential).

3.2.2. Physical properties of the material

(a) Absorption of radiation

Radiation incident upon a surface may be partly absorbed, partly reflected and partly transmitted. It is the absorbed heat which produces the temperature rise in materials, which then re-radiate according to their emissivity.

If radiation strikes the surface normally the fraction (I) absorbed is given by -

$$I = aI_o$$

i.e. $$I = I_o(1 - r - \overline{t}) \qquad (1)$$

where I_o is the incident radiation

a is the absorptivity

r is the mean reflectance,

and $\overline{t}$ is the transmittance, for a given range of wavelengths and surface conditions.

The variation of I with the angle of incidence of the radiation may be calculated from a simple geometrical law (see Section 1.3.3. Chapter 1), which states that the amount of radiation absorbed by unit area of a surface is proportional to the cosine of the angle of incidence. This law is only approximate in practice; calculations using it give slight under-estimates of damage by a given thermal dose.

If absorption cannot be regarded as wholly occurring at the surface (e.g. in the case of glass and plastics) then the Bougier-Lambert Law may sometimes apply. This states:-

$$I(x) = (1 - r)\, I\,(0) - \gamma . e^{-\gamma x} \qquad (2)$$

where x is the distance along the radiation path;

$I(x)$ and $I(0)$ are the radiant intensities at a depth x and at the surface respectively, and γ is the extinction coefficient.

γ varies with wavelength, so that the transmitted radiation may not have the same composition as the incident radiation.

As a first approximation, the temperature rise of a material is proportional to the absorbed radiation. Differences in absorptivity of the surface, particularly when "a" is small, as in the case of reflecting and transmitting materials, can be an important factor in determining thermal damage.

The absorptivity of a surface may vary considerably with wavelength, as may be seen from the example given in Figure 1. A mean value may be obtained and used for radiation characteristic of a given temperature, but a different mean value may have to be used for radiation from sources at different temperatures. This means that care must be taken in using published information, because the mean absorptivity for low temperature re-radiation is not necessarily equal to the average absorptivity for high temperature irradiation. Some values for typical materials are given in Table 1 below.

TABLE 1

Percentage absorption of different materials for different wavelengths of thermal radiation

Material	Source of Temperature			
	Ignition point	Average fire	Surface burst AW	Air burst AW
	800°K	1,100°K	3,000°K	6,000°K
	Per Cent	Per Cent	Per Cent	Per Cent
Gaberdine (Forestry Green)	-	70	65	75
Cotton Twill (White)	-	45	35	30
Cotton Twill (Grey)	60	-	65	80
Cotton Sateen (Dark)	-	40	55	75
Serge (Dark Blue)	-	65	70	85
Fibre Insulating Board	71	-	35	40
Oak	-	70	45	60
Mahogany	74	-	40	55
Steel (polished)	10	20	40	45
" (oxidised)	80	-	-	-
Copper	5	13	25	-
Aluminium (polished)	8	18	35	45
" (oxidised)	75	-	-	-

This means that whilst the colour of a material may be a guide to its reflectivity to the visible portion in the spectrum, it may not be relevant to the reflectivity in the infra-red. In addition, if the absorptivity of the surface varies with its temperature, as for example the charring of wood, discoloration of paints, surface oxidation of metal, then substantial errors may be made in estimating the temperature rise. This is particularly true for materials which have a low absorptivity, where the effects of only a slight deterioration in the surface quality can be important.

Empirical correction factors have been obtained for cellulosic materials (Reference (1)) where the changes occur gradually. These are given in Table 2. For shorter exposure times the effective absorption is less. In the absence of any other information the mean value of the initial and final absorptivities should be used.

TABLE 2

Correction Factors for Absorption
by Cellulosic Materials

Material	For time of irradiation greater than (seconds)	Effective Absorption factor for Radiation of 6000°K
African mahogany	10	0.95
Western Red Cedar	7	0.7
European Oak	10	0.7
White Cotton	3	0.3

Further data on absorptivities of metal and painted metal surfaces are given in Sections 4.3.1 and 4.3.2 respectively, of Chapter 4.

(b) Transmittance

The great majority of materials may be considered opaque to radiation. The exceptions are glass, and perspex and similar plastics, although many fabrics - especially those of loose weave and light weight - transmit some of the radiation directly, as given in Reference (8).

Few figures are available for the value of γ, the extinction coefficient, for most non-combustibles except glass (Reference (2)). Some figures which are not generally available, for plastics for wavelengths in the range 500-950 microns are given in Table 3 (from Reference (3)).

TABLE 3

Some Extinction Coefficients
of Plastic Materials

Plastic	Wavelength 500-950 microns, Extinction Coefficient (cm^{-1})
Methyl methacrylate (Perspex)	0.66
Allyl alcohol	0.32
Cellulose acetate butyrate	2.4
Cellulose acetate	1.9
Cellulose nitrate	1.3
Cellulose propionate	4.3
Ethyl cellulose	1.6
Polystyrene	2.4

TABLE 4

Thermal Constants for Various Materials

Material	Density ρ	Specific heat c	Conductivity K	Diffusivity k
	gm/cm^3	cal/gm	$cal/cm/sec/^oC$	cm^2/sec
WOODS				
Western red cedar	0.36	0.34	21×10^{-5}	1.73×10^{-3}
American white wood	0.47	0.34	29×10^{-5}	2.0×10^{-3}
African mahogany	0.56	0.34	33×10^{-5}	2.0×10^{-3}
Freijo	0.58	0.34	33×10^{-5}	2.0×10^{-3}
Oak	0.61	0.34	35×10^{-5}	2.0×10^{-3}
Iroko	0.72	0.34	41×10^{-5}	2.0×10^{-3}
METALS				
Copper	8.9	0.09	0.93	1.14
Silver	10.5	0.56	1.00	0.171
Gold	9.30	0.03	0.93	1.18
Magnesium	1.7	0.24	0.38	0.91
Aluminium	2.7	0.21	0.48	0.86
Zinc	7.1	0.92	0.27	0.111
Tin	7.3	0.53	0.15	0.038
Brass 70 : 30	8.5	0.09	0.25	0.33
Platinum	21.5	0.03	0.17	0.25
Lead	11.3	0.03	0.08	0.25
(0.1%C) mild steel	7.9	0.12	0.11	0.12
Cast iron	7.4	0.14	0.12	0.12
Bismuth	9.8	0.03	0.02	0.07
Mercury	13.6	0.03	0.02	0.04
BUILDING MATERIALS				
Fibre insulating board	0.24	0.34	8.5×10^{-5}	1.04×10^{-3}
Brick	1.44-2.24	0.20-0.22	$13\text{-}32 \times 10^{-4}$	$44\text{-}67 \times 10^{-4}$
Concrete (gravel)	2.16-2.29	0.22-0.23	$57\text{-}33 \times 10^{-4}$	$65\text{-}120 \times 10^{-4}$
Foamed slag concrete	1.04	0.23	5.7×10^{-4}	24×10^{-4}
Cellular concrete	0.64	0.25	3.4×10^{-4}	21×10^{-4}
Glass	2.11-2.6	0.16	2.1×10^{-3}	5.2×10^{-3}
Slag wool	0.19-0.30	0.18	$0.9\text{-}1.4 \times 10^{-4}$	$26\text{-}27 \times 10^{-4}$
BOARDS OR BLOCKS				
Asbestos paper				
Corrugated	0.25	0.24	1.46×10^{-4}	24.2×10^{-4}
Laminated	0.35	0.24	1.5×10^{-4}	18×10^{-4}
Corkboard	0.13	0.42	1.0×10^{-4}	18×10^{-4}
Fibre glass	0.032	0.13	8.5×10^{-5}	1.9×10^{-2}
POWDERS				
Charcoal	0.18	0.25	1.2×10^{-4}	26.8×10^{-4}
Ground cork	0.15	0.48	1×10^{-4}	0.0014
Soil (Average)	2.5	0.2	23×10^{-4}	0.0046
Soil (Sandy dry)	1.65	0.19	6.3×10^{-4}	0.0020
Soil (Sandy moist 8%)	1.75	0.24	14×10^{-4}	0.0033

3.3. Calculation of the temperature rise of an irradiated slab

It is assumed that:-

(a) the absorptivity of the surface is constant;

(b) the energy is absorbed at the surface;

(c) the material is dry and inert;

(d) the material is homogeneous.

The temperature rise θ, of a solid bounded by two parallel planes (a slab) of thickness $2l$, losing heat from both faces by Newtonian cooling, and exposed on one face of absorptivity a to a constant intensity of radiation I, is obtained from:-

$$\frac{\partial^2\theta}{\partial x^2} = \frac{1}{k}\frac{\partial\theta}{\partial t} \qquad (t > 0) \qquad (1)$$

$$\frac{aI}{K} = h\theta + \frac{\partial\theta}{\partial x} \qquad (x = +l) \qquad (2)$$

$$h\theta = -\frac{\partial\theta}{\partial x} \qquad (x = -l) \qquad (3)$$

$$\theta = 0 \qquad (t = 0) \qquad (4)$$

where $h = \frac{H}{K}$

H is the Newtonian cooling constant

k is the thermal diffusivity $= K/\rho c$

K is the thermal conductivity

ρ is the density

c is the specific heat of the irradiated material

t is the irradiation time

x is the distance within the solid

The solution to these equations is complex (References (1) and (2)). However, within certain ranges of values of two dimensionless groups, the Fourier number kt/l^2, and the Biot number hl, useful approximations may be made. These are shown diagrammatically in Figure 1.

(i) The uniform slab

For the region A, in Figure 1, there are in effect no temperature gradiants within the solid. The mean temperature rise θ_M and the surface temperature rise θ_F are given by:-

$$\theta_F = \theta_M = I/2H \left(1 - e^{\frac{-Ht}{\rho cl}}\right) \qquad (5)$$

4.2. Critical Energy Data for Combustible Materials

4.2.1. Textiles

Small specimens of various textiles were exposed at Operation Buffalo to the heat flash from Round I (about 15 KT), and the extent of the damage observed is summarised briefly in Table I, for a selection of the materials used. The following general conclusions are made in Reference (1) from consideration of the extensive thermal data obtained at Operation Buffalo.

(i) Materials which decompose without melting, or before melting begins (e.g. cotton, wool, etc.) afford better protection to the underlying skin that those that melt or are softened on exposure to heat (e.g. nylon, polyvinylchloride and synthetic fibres generally).

(ii) Resistance to damage by thermal radiation generally increases with increasing weight per unit area of the material, and several layers are much superior in this respect to a single layer of the same total weight.

(iii) White or light-coloured materials suffer less damage than dark materials, but thin white materials transmit the radiation to the underlying layers more readily than do dark-coloured materials. Thin white materials in contact with black underlying layers are damaged by heat sooner than when the underlayer is white.

(iv) In fabrics composed of a mixture of cotton and nylon there is an indication that resistance to damage is slightly reduced by the presence of nylon, owing to acceleration of the rate at which heat damage occurs.

(v) Terylene only improves the heat resistance of wool marginally.

(vi) Flameproofing does not affect the flashing of fabrics.

In Table 2 (taken from Reference (2)), the critical radiant exposures for specified damage to various fabrics are shown for three weapon yields. These values apply for an ambient relative humidity of 65% and an ambient temperature of 20°C. For extremely dry conditions the values shown for fabrics should be reduced by 20%. For extremely high relative humidity, near 100% at 20°C, the values for fabrics should be increased by 25%. If the fabrics are water soaked, the critical radiant exposures should be increased by 300%. It should be emphasized that the values in Table 2 for uniforms refer to damage to the material itself, and are not applicable for predicting skin burns under uniforms.

A correlation of these results is shown in Figure 1 of Section 4.1, from which the threshold conditions for damage to other materials may be estimated, (Reference (3)). White materials require about twice as much energy for total destruction as other materials. There does not appear to be any significant difference between different types of material, sizes of bomb, or origins of results.

References

(1) A.W.R.E. Report T12/58. Operation Buffalo Target Response Tests, Materials Group. Part 2: "Effects on Textiles". (Confidential)

(2) Capabilities of Atomic Weapons. U.S. Department of the Army. TM23-200 p.12-3 (Confidential)

(3) Thomas, P. H. and Simms, D. L., "Correlation of field data for total destruction of fabrics by nuclear explosions." Joint Fire Research Organisation". S.R. Note No. 36/1958. (Confidential)

TABLE I - Damage to Miscellaneous Textiles by Thermal Radiation from an Approximately 15 KT Weapon

Material	Thickness in.x 10^{-3}	Weight oz/yd^2	Calories/cm^2		
			Incipient damage	Serviceability just retained	Total Destruction
Cotton duck, waterproofed, olive drab	26	15	6	12	24
ditto, fireproofed	29	22.4	8	12	48
Cotton canvas, plain olive drab	37	24.1	3	16	32
ditto, waterproof	39	24.7	4	64	>128
Hessian, brown	64	12.4	4	8	32
" green	58	12.6	3	8	16
" black	63	13.1	4	6	16
100% wool, cavalry twill fawn	52	14.3	3	6	>48
15% nylon, flannel grey	22	6.6	3	3	12
50% nylon, flannel grey	20	5.3	2-3	2	12
100% nylon, plain weave fawn	20	7.2	8	8	16
100% wool twill, white	28	9.0	4	12	32
20% terylene wool twill white	25	8.6	12	24	32
60% " " "	22	7.8	12	16	24
100% terylene twill white	19	7.6	8	8	24
100% cotton plain cloth pale blue	10	5.1	8	16-24	32
32% nylon " "	10	5.1	12	16	24
Serge battledress, khaki	50	14.5	4	12	32
Sateen combat suit, olive drab	20	8.8	4	6	24
Drill, cotton, khaki	23	7.3	6	6	12

TABLE 2 - Critical Radiant Exposure Values for Various Fabrics
(S = Scorched, D = Destroyed)

Uniforms	Colour	Weight (oz/yd^2)	Damage	Critical Radiant Exposure $cals/cm^2$		
				1 KT	100 KT	10 MT
Army						
Cotton twill fatigue	Green	8	S	3	5	9
			D	8	14	25
Wool serge (winter service)	Olive Drab	9	S	3	6	10
			D	21	37	66
Wool flannel	Olive Drab	11	S	3	5	8
			D	20	40	70
Wool tropical worsted	Khaki	11	S	6	9	13
			D	13	20	30
Cotton twill shirt and trousers (summer)	Khaki	6	S	4	6	11
			D	18	31	56
Navy						
Cotton twill (working)	Khaki	8	S	3	5	8
			D	15	26	46
Cotton denim (dungaree)	Blue	9	Nap S	6	10	17
			D	7	13	23
Cotton chambray shirting (working)	Blue	3	S	3	6	11
			D	7	13	22
Cotton twill (white uniform)	White	8	S	4	8	14
			D	34	60	109
Wool, Melton (dress blues)	Blue	16	S	1	16	13
			D	9	18	28
Wool, Kersey (overcoat)	Blue	30	S	1	2	3
			D	37	65	110
Wool, serge (officer's uniform)	Blue	14	S	5	9	16
			D	11	21	37
Wool, tropical worsted (officers' uniform)	Khaki	11	S	5	9	16
			D	11	20	37
Vinyl resin, combined (rain)	Black	13	S	1	1	2
			D	5	6	8
Marine Corps						
Cotton poplin shirting	Olive Drab	6	S	3	6	10
			D	10	18	32
Wool elastique (winter)	Green	16	S	2	4	7
			D	25	45	80
		21	S	5	8	15
			D	30	54	95
Wool, Kersey (winter)	Green	16	S	2	3	6
			D	27	48	85
Wool, serge	Green	12	S	2	3	6
			D	16	28	50

TABLE 2 (Contd.)

Uniforms	Colour	Weight (oz/yd^2)	Damage	Critical Radiant Exposure $cals/cm^2$		
				1 KT	100 KT	10 MT
Air Force						
Cotton twill shirt (tropical)	Khaki	5	S	6	10	19
			D	9	15	27
Wool gabardine shirt	Grey	8	S	10	17	28
			D	14	22	37
Wool gabardine shirt	Blue	8	S	1	2	4
			D	8	14	25
Nylon - flying jacket	Olive Drab	5	S	2	3	6
			D	7	13	23

4.2.2. Plastics

Small specimens of various plastics were exposed at a number of sites at Operation Buffalo to the heat flash from an approximately 15 KT explosion (Reference (1)). The types of materials used were:-

1. Polythene sheet, low and high pressure variety, normal, black, and irradiated (thickness 0.061-0.069 inch).

2. Polyvinylchloride sheet of varying colour and platiciser content (thickness 0.059-0.085 inch).

3. Nylon sheet of varying grade and colour (thickness 0.128-0.131 inch).

4. Phenolic mouldings and laminates with various fillers (thickness 0.060-0.121 inch).

5. Glass fibre resin laminates. Different resins. (Thickness 0.061-0.069 inch).

6. High impact polystyrene, varying colours and fillers (thickness 0.065-0.151 inch).

7. Polytetrafluorethylene (P.T.F.E.) (thickness 0.126 inch).

8. Polychlorotrifluorethylene (P.C.T.F.E.) (thickness 0.058 inch).

After exposure, the samples were examined visually and mechanical tests were carried out where possible. The tests employed were tensile strength and elongation at break, flexural strength in 3-point bending, shear strength and hardness. Full details of these plastics and the mechanical test results are given in Reference (1).

The results obtained are based on only one specimen exposed at each site. Some anomalies may therefore be expected in the results owing to the variability of the materials themselves and to damage which may have arisen due to the positioning. Nevertheless, there are definite trends in the results, and some general conclusions can be drawn.

(i) The plastic materials generally withstood the exposure conditions rather better than would have been expected from consideration of their stability when heated at low intensities for long periods. In the group of thermo-plastic materials, the relative performance of the high and low softening point polymers was comparable.

(ii) Colour affected the behaviour of the specimens. In general, the black materials embrittled at much lower calorie doses than the light-coloured samples. The effects on the natural polymers, normally off-white in colour, and of those formulations containing white pigment, were very similar.

(iii) In the case of phenolic mouldings and laminates, the type of filler influenced the results. The glass and asbestos-filled laminates were least affected. The silver-coloured high impact polystyrene (filled with aluminium powder) was more distorted than other polystyrene samples, but the fall in flexural strength was of the same order.

(iv) The materials least affected by the exposure were the fluorine containing polymers P.T.F.E. and P.C.T.F.E., and some of the glass-fibre resin laminates. These samples were only slightly marked at the maximum thermal flux of 128 cals/cm^2. The fire-resistant polyester glass-fibre laminates however, showed some surface deterioration in the range 32-48 cals/cm^2, and a drop in flexural strength of 30% at a dose of 96 cals/cm^2.

(v) For the majority of the materials the critical point for visual surface damage was in the range 12-24 cals/cm^2. At thermal fluxes below this level, slight changes in the surface texture such as bleaching, polishing, or delineation of the exposure area, were evident in many oases. By visual assessment, the materials could be rated according to the thermal flux at which marked surface deterioration first occurred. It is evident from the results of the mechanical tests however, that the damage was, in the main, confined to the surface, and that the bulk of the material was unaffected. This is understandable in view of the poor thermal conductivity of plastics in general.

Some American data from Reference (2), on the behaviour of certain plastics to thermal radiation from nuclear explosions, is given in Table I below.

TABLE I

Material	Damage	Critical Radiant Exposure calories/cm^2		
		1 KT	100 KT	10 MT
Laminated methyl methacrylate	Surface melts	73	120	230
U.S.A.F. window plastic ($\frac{1}{2}$ inch)	Bubbling	240	430	750
Vinylite (opaque) ($\frac{1}{8}$ inch thick)	(Dense smoking (Flaming	3 20	4 20	6 25

References

(1) A.W.R.E. Report T18/58. Operation Buffalo Target Response Tests, Materials Group, Part 3 : Effects on Plastics. (Confidential)

(2) Capabilities of Atomic Weapons. U.S. Department of the Army, TM 23-200, page 12-4. (Confidential)

4.2.3. Rubbers

Service and civilian respirator rubbers were exposed at Operation Totem, and the results are summarised in Table I (Reference (1).

TABLE I - Effects of Thermal Radiation on Respirator Rubbers

Material	Total Incident Thermal Energy, cal/cm^2				
	7	11	21	35	63
G.S. Respirator rubber (1.9 mm thick)	Not Exposed	Flashed, Surface-melted	Flashed and burned	Flashed and burned fiercely	Flashed and burned fiercely
Civilian Respirator rubber (0.9 mm thick)	Very slight melting on front surface	Flashed, Surface-melted	Flashed and burned	Flashed and burned fiercely	Flashed and burned fiercely

This trial demonstrated that the risk to the wearer of a Service respirator of being burned by heat conduction through the rubber, was slight, but that there was some danger of this happening with the civilian respirator. The eye-piece of the Service respirator transmitted about 60% of the incident radiation; consequently the eyes and the areas surrounding the eyes will be susceptible to serious burn injury from explosions occurring in front of the wearer, at ranges beyond those corresponding to significant respirator damage. (See Chapter 7, Sections 7.2 and 7.8).

At Operation Buffalo, specimens of various types of rubbers were exposed to the thermal flash from an approximately 15 KT weapon (Reference (2)). A comparison was made of the behaviour of four rubbers - natural, polychloroprene, butadiene acrylonitrile (nitrile) and butadiene isoprene (butyl).

Each rubber was represented by specimens in three colours - black, white, and olive drab. Specimens of heavy and light cotton fabrics proofed with natural rubber and neoprene compounds, were exposed in order to assess the behaviour of relatively thin coatings of rubber.

The most obvious effect of exposure on the four types of mechanical rubber was contamination by desert sand of the specimens at the sites nearest to ground zero. This was apparently the result of thermal softening of the surface of the rubber, to which sand adhered through the ensuing blast. The heaviest contamination occurred mainly at a thermal dose of 96 cals/cm^2, rapidly decreasing with lower doses, and not occurring at all doses of less than 6 cals/cm^2. The colour of the rubbers also affected the surface contamination, which decreased in the order black, olive drab, white.

Mechanical tests (tensile strength and elongation at break) were carried out on many of the exposed specimens, with the results summarised briefly below.

Natural Rubber - The effect of thermal dose was less noticeable with increasing carbon black loading, and at the highest loading (100 parts black per 100 parts rubber) there was no significant effect attributable to heat. In the white and olive drab samples the effect of thermal dose was very slight and was less in the case of olive drab than of white samples.

Polychloroprene Rubber - Elongation at break appeared to be little affected by thermal dose, but there was marked reduction of the tensile strength of the black specimens at thermal doses above 6 cals/cm^2. It was considered however, that all the samples would have been serviceable for reasonably long periods. There was no significant effect on any of the white samples, nor on the olive drab samples exposed to doses of 64 cals/cm^2 or less.

Nitrile Rubber - The effect of exposure on the elongation at break and tensile strength of the black nitrile rubbers was of little significance at thermal doses below 128 cals/cm^2, and although there was some reduction at this figure (the highest thermal dose) the results were still within specification limits. Anomalous results however, were obtained with the white and olive drab samples, the elongation at break and tensile strength improving with increasing thermal dose up to 32 cals/cm^2, followed by a very slight fall. It is considered that the white samples would have been unusable, but that the olive drab would be capable of very limited use.

Butyl Rubber - In no case was there any significant effect on the elongation at break. On tensile strength, there was a marked effect at thermal doses of 96 cals/cm^2 and above, but at doses lower than this the results showed hardly any significant change. It is considered that all the samples would still have been serviceable.

The general conclusion drawn from the examination and testing of specimens is that the nature of the polymer and the colour of the material are the two main factors which influence degradation. On a colour basis, the rubbers displayed increasing resistance to thermal radiation, from white through olive drab, to black, (i.e. black samples most resistant). Of the polymers exposed, natural rubber showed the best resistance, followed by butyl and polychloroprene, with nitrile rubbers as the most seriously affected.

References

(1) A.W.R.E. Report T77/54. Effects on Respirators Anti-Gas. (Confidential)

(2) A.W.R.E. Report T16/58. Operation Buffalo. Target Response Tests. Materials Group, Part 4 : Effects on Rubbers. (Confidential)

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4.2.4. Packaging Materials

Small specimens of sheet packaging materials were exposed to the heat flash from an approximately 15 KT weapon at a number of sites at Operation Buffalo. Multi-wall and hessian sacks filled with sand, lengths of rope of various fibres, and thermal screens of ground sheets and camouflage nets, were exposed to both heat and blast at several sites. Full details of the results will be found in Reference (1), but a summary of the main conclusions is given below.

Sacks - Sacks made of laminates of Kraft and bitumen Kraft union showed increasing depth of damage with increasing heat dose. The outer laminates were almost completely destroyed before the inner laminates were seriously affected. This survival of the lower layers indicates the value of a thermal screen built up of inflammable sheets supported by thin air gaps, and is confirmed by the damage sustained by the uncovered sand-filled hessian sacks. None of the paper sacks was holed by the heat flash up to a dose of 24 cals/cm^2, while the hessian sacks had spilled contents at 16 cals/cm^2. Temperature indicators which were placed behind the specimens in the exposure frames, recorded no temperature rise above 80°C behind the Kraft laminates on any site, while the temperature rose to at least 100°C at the 8 calorie site, increasing to 170°C at 48 calories, behind the hessian with a cotton underlayer, and to 140°C and 190°C at the same sites behind a single hessian layer.

Tarpaulins - Tarpaulins gave excellent protection against heat to all sacks with which they were placed, on sites where blast did not cause additional damage, but tentage similarly placed, caused more damage through catching fire than resulted from the heat flash alone.

Fibre Boards - Carton board and corrugated board showed the value of air-spaced laminates in a manner similar to that shown by the sacking. The building paper Sisalkraft and polymer transparent sheets showed a resistance to heat damage consistent with their construction, but the value of a metal foil coating in protecting paper from heat damage was very striking.

Timbers - There was no difference in the degree of burning shown by planed and unplaned samples of the same wood. The hard woods were slightly more sensitive to incipient scorching (at 8-12 cals/cm^2) than the soft woods, but were less deeply charred at the higher heat doses (up to 128 cals/cm^2).

Spray-Packaging Materials - A skin made solely from the vinyl plastics used for short-term packaging, suffered complete destruction at only 6 cals/cm^2, while the vinyl/bitumen skin with aluminium paint used for full protection suffered only surface damage up to at least 64 cals/cm^2, after which the specimens were torn by blast.

Ropes - The sisal ropes, both untreated and rot-proofed, showed some scorching after 8-12 cals/cm^2, but did not materially lose strength until the thermal dose exceeded 24 cals/cm^2, when the breaking loads showed an erratic loss of strength of about 20% to 30%, probably due to blast rather than heat. The terylene and nylon ropes showed no damage at thermal doses below 12 cals/cm^2. At higher doses, there was a proportional increase in loss of strength up to 50% at about 100 cals/cm^2, with corresponding signs of fusing of the polymer fibres.

References

(1) A.W.R.E. Report No. T29/58 Operation Buffalo Target Response Tests. Materials Group, Part 7. "Effects on Packaging Materials". (Confidential)

4.2.5. Paints

Samples of paints of formulations selected for heat resistance were applied to small plates of various metals, and exposed to the heat flash from a weapon of about 15 KT at Operation Buffalo. (Reference (1)).

Paint films applied to steel plates had the following formulations:-

(a) 1 coat green. Epoxide resin araldite 985E

(b) 1 coat aluminium. Epoxide resin araldite 985E

(c) 1 coat primer. Zinc pigmented butyl titanate
1 top coat. Aluminium pigmented butyl titanate.

(d) 1 coat green. Silicone resin.

(e) 1 coat aluminium. Silicone resin.

(f) 1 coat green. Silicone alkyd.

(g) 1 coat aluminium. Silicone alkyd.

(h) 1 coat primer DEF 1035
1 coat undercoat DEF 1044
1 top coat DEF 1044 green

(j) 1 coat primer DEF 1035
1 coat undercoat DEF 1044
1 top coat DEF 1044 type alkyd medium, aluminium

(k) 1 coat aluminium paint to CS 1199.

(l) 1 coat "Alifuse". Zinc/aluminium pigmented butyl titanate

No change in the paint layers was visible on specimens receiving heat doses up to 12 cals/cm^2. Some of the specimens on the sites nearest the ground zero were scattered by blast and not recovered. The remainder of the specimens showed the effects described in Table 1 below.

TABLE I

Thermal Damage to Paints on Steel Plates

Paint	Incident Thermal Dose (Cals/cm^2)						
	16	24	32	48	64	96	128
a. Epoxide Green	NC	NC	NC	Sl.loss	-	-	-
b. Epoxide	NC	Sl.Dc.	Sl.Dc.	Sl.Dc.	Marked Dc.	Marked Dc.	Film mechanically damaged.
c. But. Titanate 2 coats	NC	V.sl. Dc.	Sl.Dc.	Marked Dc.	Marked Dc.	-	Heavy Dc.
d. Silicone Resin Green	NC	NC	NC	Sl.Dc.	Sl.colour change Blistered	Marked darkng. Blistered	Film almost completely destroyed
e. Silicone Resin Aluminium	NC	NC	V.Sl. Dc.	Marked Dc.	Marked Dc.	Marked Dc. Pitted	Marked Dc. Pitted
f. Silicone Alkyd Green	NC	NC	NC	Darkng sl. blistering	As 48	As 48	As 48 Brown stain
g. Silicone Alkyd Aluminium	NC	NC	V.Sl. Dc.	Sl.Dc. some pitting	Marked Dc. some pitting	As 64	As 64
h. DEF 1044 Green	V.sl. darkng.	Sl. darkng.	Severe darkng.	Blackened	Blackened Erosion	-	Dark grey Erosion
j. DEF 1044 Aluminium	NC	NC	V.sl. Dc.	Marked Dc.	Marked Dc. some pitting	-	Marked Dc. Some pitting
k. CS 1199 Aluminium	NC	V.sl. Dc.	V.sl. Dc.	-	Sl.Dc. pitting	As 64	As 64
l. "Alifuse"	V.sl. Dc.	NC	V.sl. Dc.	Marked Dc. Pitting	Sl. Dc. pitting	As 64	As 64

NC = No change
Dc = Discolouration
V = Very
Sl = Slight

None of the paints listed in Table 1 showed any effect from heat doses below 16 cals/cm^2. Results at higher doses indicated that:-

1. A paint pigmented with aluminium is more resistant to heat flash than one with a green pigment.

2. Of all the paints exposed, those based on butyl titanate show greatest resistance to heat flash.

3. In comparing paints made from epoxide "araldite" resin, silicone resin, and silicone alkyd, the epoxide resin paints showed greatest resistance to heat flash.

In an additional series of tests at Operation Buffalo, specimens of paints applied to magnesium, titanium, steel and aluminium alloy plates were exposed to thermal flash of various intensities from a 15 KT explosion. Strips of heat-sensitive paints were applied to the backs of the plates to record the maximum temperature reached. Most of the specimens were samples of standard aircraft paint schemes. There were also some unpainted samples of polished metals, including silver plated steel and electro-polished aluminium ("Brytal"). Many of the plates located on sites receiving 96 and 64 cals/cm^2 were blown away, and those reamining were badly damaged by sand blasting. This prevented any precise appraisal of thermal damage, but generally the white paints were unaffected, whereas silver paints (i.e. aluminium pigments) showed obvious blistering. From sites receiving 48 and 32 cals/cm^2, the white and silver paints did not show any thermal damage, as the dose was insufficient to affect them. However, the brown-painted samples from these sites were severely burned.

References

(1) A.W.R.E. Report T27/58. Operation Buffalo Target Response Tests, Materials Group. Part 5 : Effects on Paints. (Confidential)

4.3 Absorption of Heat by Metallic Surfaces

The procedure for estimating the thermal dose to a surface is given in Section 1.3 of Chapter 1, and a discussion of the factors which influence the temperature rise of irradiated materials is given in Chapter 3. Some values of the temperature rise of irradiated surfaces have been obtained (References (3)).

Absorption data for sunlight and carbon arc radiation are presented in the following sections. The figures give a good general picture of what the initial absorption of fireball radiation is likely to be, but they should not be used for refined calculations. In particular, they do not indicate any change of absorption coefficient with dose absorbed. Ideally, we require relationships between the total incident does and total dose absorbed for each surface. As such data are not yet available, the present data are provided as an interim measure.

4.3.1. Absorption by Bare Metallic Surfaces

The absorptivity of a polished metal surface will be increased by roughening, and by dirt or corrosion. The influence of the state of the surface (polished or rough, oxidised or machined, etc.) can be seen from Table 1 below, which is taken from Reference (1). Whereas a trace of oxide (tarnishing) does not appreciably change the absorptivity, thick oxide layers raise it considerably. Heavily oxidised and very rough surfaces approach the behaviour of a black body. The values given in Table 1 may hold up to 200°C. For higher temperatures, too, they will not change much.

Table 1

Influence of the State of Surface of Metals upon the Absorptivity at 25°C

Substance	State of Surface	Percent Absorptivity
Copper	Polished	3
	Polished, slightly tarnished	3.5
	Shaved	7
	Oxidised black	78
Brass	Polished	4
	Polished, slightly tarnished	4.5
	After rolling	6
	Fresh rubbed with abrasive	20.5
Tin	Iron sheet, tinned	5.5
	Iron sheet, nickel plated, polished	4.5
	Iron sheet, nickel plated, dull	11
Zinc	Iron sheet, zinc plated, bright	24
	Iron sheet, zinc plated, grey	27.5
Iron	Sheet, newly treated with abrasive	24
	Cast, newly machined	43.5
	Sheet, stained	65
	Steel sheet, with skin due to rolling	66
	Steel sheet, with rough or brilliant oxide layer	81
	Cast, with smooth or rough cast skin	81

Some data on the absorption of radiant heat by metal surfaces, derived in part from Reference (2) are given in Table 2.

Some additional data on the absorptivities of steel, copper and aluminium for different wavelengths of thermal radiation are given in Table 1 of Section 3.2.2, Chapter 3.

References

(1) "Heat Transfer" M. Jakob, Vol.I p.126 (John Wiley, 1949)

(2) "The Calculation of Heat Transmission".
M. Fishenden and O. A. Saunders, (H.M.S.O. 1932)

(3) Smith P. G., "Temperature Gradients in Painted and Unpainted Metals Subject to High Intensity Thermal Radiation Pulses".
Joint Fire Research Organisation - S.R. Note No. 32/1957
(Confidential)

TABLE 2

ABSORPTION OF RADIANT HEAT BY METAL SURFACES

Metal	Percentage Absorption of Radiation from		
	Sun	Carbon arc Note (i)	Fireball (Note (ii)
Aluminium, superpurity electro-polished			14
Aluminium, pure, mechanically polished		11	
Duralumin	53		
Chromium plate	49		
Copper, mechanically polished			
Speculum metal, mechanically polished	39		
Gold, polished			
Iron, pure, polished	45		
Steel, polished	45		
Stainless steel			
Red Oxide of Iron	74		
Nickel, electrolytic	40	33	
Monel metal	43		
Platinum, pure	50		
Platinum, black	97		
Silver, polished	11	22	8
Tin		25	
Titanium		56	
Zinc, polished	46	48	

Note:- (i) These figures are probably too low as the metallic reflector to the arc removes near-ultra-violet radiation strongly absorbed by some polished metals, notably Al, Ag, Cr.

(ii) Preliminary calculation for a fireball at 6500°K.

4.3.2. Absorption by Painted Metal Surfaces

(a) Effect of pigment colour

The colour of the pigment will largely determine the degree of absorption, and values for a number of pigments are given in Table I for Solar Radiation (Reference (1))

Table 1

Absorption of Radiant Heat by Pigments

Colour	Material	Percent absorption of radiation from the sun
Black	Soot	99
Blue	Cobalt oxide	97
Green	Chromic oxide	73
Yellow	Lead chromate	30
Yellow	Lead oxide (PbO)	48
Red	Iron oxide	74
White	Alumina	16
White	Lead carbonate	12
White	Magnesia	14
White	Magnesium carbonate	15
White	Thoria	14
White	Zinc oxide	18

(b) Effect of the nature of pigment in white paint

A white pigment is a powder form of a transparent material which reflects a high total proportion of incident radiation by successive small reflections. As many paint media absorb radiation in the invisible portions of the spectrum, it follows that the reflective efficiency of a white paint depends to a considerable extent on the capacity of each pigment particle to reflect a high proportion of the radiation and thus limit the length of path of the radiation through the paint. The reflection coefficient of a pigment/medium interface is given by:-

$$\text{Reflection coefficient} = \frac{(\mu_p - \mu_m)^2}{(\mu_p + \mu_m)^2}$$

where μ_p is the refractive index of the pigment
and μ_m that of the medium.

The refractive indices of common white pigments are listed in Table 2 below.

Table 2

Pigment	Refractive Index
Silica	1.55
China clay	1.56
Whiting, calcium carbonare	1.58
Anhydrite, calcium sulphate	1.59
Mica	1.59
Talc	1.59
Blanc fixe, barium sulphate	1.63
Magnesium carbonate	1.64
White lead	2.0
Zinc oxide	2.0
Zinc sulphide	2.37
Titania, anatase	2.5
Titania, rutile	2.75

The refractive indices of paint media lie generally between 1.5 and 1.6. Slight increases occur during weathering.

In the commoner types of paint media, only those white pigments with refractive indices of two or more are efficient reflectors. Air voids greatly improve the reflectivity of a pigment, for at pigment/void interfaces $\mu_m = 1.0$. Whitewash and some distempers fall into this class.

The results of an investigation (Reference (2)) on paints are given in Table 3. The carbon arc absorption figures for the aluminium pigmented paints in this Table are probably too low, since the metallic reflector to the arc removes near ultra violet radiation. The following conclusions may be drawn from Table 3:-

(i) The absorptivity of finishes pigmented with rutile titania is about 25 to 30%. With multiple finishing coats, the figure can be reduced to near 20%, but at the expense of heat stability.

(ii) Nitro cellulose media tend to break down at relatively low temperatures, and to do so by rapid charring.

(iii) Stoving paints are more stable to heat than air-drying paints. The blistering of air-drying paints may be associated with solvent retention, especially where multiple coats have been applied. It is probable that a light stoving would increase the thermal stability of air-drying schemes.

American work on white paints (Reference (3)), has given the following results:

(i) Rutile titania was more reflective than anatase.

(ii) Silicone/alkyd media gave the greatest thermal stability.

(iii) Reflectivity increased markedly with increasing pigment/volume concentration.

(iv) Reflectivity increased with increase in the total thickness of the coating, 6 mils (0.006") being superior to 4 mils, which were, in turn, superior to 2 mils. There was no advantage in thicknesses greater than 6 mils.

(v) Reflectivity was increased by replacing part of the rutile titania by zinc oxide or china clay.

(vi) In schemes of total thickness of 2 mils, the colour of the primer had some effect, as whitening of the zinc chrome primer by addition of titania and china clay improved the reflectivity. It is not known whether the colour of the primer has any influence when it is covered by multiple finishing coats.

The reflectivities of rutile pigmented white cellulose and synthetic paint schemes (D.T.D.899A and D.T.D.827) for aircraft have been determined over the wavelength range 0.32 to 2.2 microns (Reference (4)). These schemes consist of varying weights of finish coats over a selection of filler type undercoats. The results indicate that the absorption of thermal energy occurs mainly in the rutile pigment. It is concluded that further improvement in reflectivity is unlikely whilst rutile is used as the sole pigment. However reflection of the energy in the ultra-violet (less than 0.4 micron) by a surface layer with no absorption of the energy in the visible and infra-red could increase the overall efficiency of the scheme to a nominal 95 per cent. The tests show that for these types of paint any increase in weight of the finish coat above 4 oz/yd^2 will not materially increase their reflective efficiency for radiation from a black body at 6000°K.

(c) Selection of paints

A single coat of paint applied by normal brushing or spraying technique weighs when dry, about 1 oz. per sq. yard, and has a thickness of about 1 mil. In calculating the temperature rise of painted metal, it should be assumed that the absorption figures quoted in Table 3 already include the effect of heat insulation due to the poor heat conductivity of the paint film.

The best paints for protection against heat flash consist of heat resistant media pigmented with titania and other white pigments which have absorptions of the order of 20 to 25%. It is hoped that current research will reduce this figure to about 17.5%. See also Reference (7).

It may be assumed that the absorption will rise rapidly as the paint scorches, reaching a figure of 60 to 90% when the paint chars.

Colours can be divided into two classes. For dark colours thermal stability is only of importance in so far as it is required to maintain the paint as protection against corrosion; charring will only raise the percentage of absorption of heat from a high value to a higher one. For colours of medium reflectance however, thermal stability of the paint is very important, for total heat absorption of a moderate absorber stable to high temperature could be less than that of a low absorber which breaks down at relatively low temperatures to become a high absorber. Some flame retardant treatments are mentioned in Chapter 6, Section 6.3 (iv).

(d) Skin temperature rise in aircraft

The skin temperature rise in an aircraft exposed to thermal radiation from a nuclear explosion is discussed in Reference (5). It is shown that in many situations aerodynamic cooling substantially reduces the temperature rise in thin skins of aircraft exposed in flight to thermal radiation from nuclear explosions. The maximum acceptable thermal dose, where this is determined by skin temperature rise, depends upon the time scale of the thermal input, and this upon the yield of the weapon involved.

In Reference (5) the problem is attacked by a finite difference analysis, and the maximum temperature rise and the time at which it occurs are shown to depend on a single non-dimensional parameter. The results are presented for a range of this parameter corresponding to the majority of practical situations.

The effects of non-uniform absorptivity of thermal radiation on the temperature rise in aircraft skin (e.g. under insignia) have been examined and are reported in Reference (6). Some recent tests of heating under load are reported in Reference (7).

References

(1) "The Caluclation of Heat Transmission". M. Fishenden and O. A. Saunders. (H.M.S.O. 1932).

(2) R.A.E. Farnborough (Chemistry Dept.) Unpublished Work.

(3) Vita-Var Corporation "Investigation of Protective Coatings to Decrease Vulnerability of Aircraft to Thermal Radiation". 1st, 2nd and 3rd quarterly reports (1954/55) (Confidential/Discreet) T.I.L. Nos. P.55101/2/3.

(4) R.A.E. Tech. Note Chem. 1323 (November, 1957) The Reflectivities of Rutile Pigmented White Paint Schemes for Aircraft over the Wavelengths 0.32 to 2.2 microns (Restricted)

(5) R.A.E. Tech. Note Mech.Eng. 251 (March, 1958) - Skin Temperature rise in an Aircraft exposed to Thermal Radiation (Confidential)

(6) R.A.E. Tech. Note Mech.Eng.268 (July, 1958) - The Effects of Non-Uniform Absorptivity of Thermal Radiation from Nuclear Explosions on the Temperature Rise in an Aircraft Skin. (Confidential)

(7) R.A.E. Test Note Structures 1519. July, 1958. Combined Transient Heating and Static Loading Test of a Valiant Aileron. (Confidential)

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TABLE 3

ABSORPTION BY REPRESENTATIVE PAINT SCHEMES ON METAL SURFACES

Paint Scheme	Primer	Filler	Finish	Pigment in finish	Percent Absorption of radiation	Onset of deterioration in arc, ^{o}C
					Carbon arc	
Nitrocellulose finish						
DTD.766A	Etch	None	Alkyd.N/C	Pol.Al.flake	39	200 S
DTD.722	Alkyd.X2	None	Alkyd N/C	Rut.TiO_2	35	150 Bl.C
DTD.722 Finish polish	Alkyd.X2	None	Alkyd.N/C	Rut.TiO_2	35	150 Bl.C
DTD.754	Etch	None	N/C	TiO_2+ SiO_2	30	230 S
Air Drying Alkyd						
Mat. DTD.314	Etch	None	Alkyd	TiO_2 + SiO_2	26	250 S
Glossy DTD.827	Etch	Alkyd + China clay	Alkyd	Special I.R. reflectors	54	200 Bl.S
"	"	"	"	Al, non-leafing	42	200 Bl.S
"	"	"	"	Al, leafing	40	200 Bl.
"	"	"	"	Al.polished	34	180 Bl.C
"	"	"	"	TiO_2	27	170 S
"	"	"	"	TiO_2 + SiO_2	27	180 Bl.S
"	"	"	Alkyd - 3 coats	TiO_2	22	150 Bl.S
Stoving Alkyd U/F						
DTD.235	Alkyd	None	Alkyd U/F	TiO_2 + SiO_2	30	250
Epoxy, cold catalysed						
DTD.900/4414	Epoxy	None	Epoxy	TiO_2	27	230 S
Epoxy, stoving						
-	Epoxy	None	Epoxy P/F	TiO_2	35	230 S
Silicone Air drying						
Mod. of DTD. 900/4381	None	None	Silicone	White	30	200 S
"	Etch	None	Silicone	White	35	200 S
Silicone stoving						
-	Silicone	None	Silicone	Pol.Al.flake	37	250
-	Silicone	None	Silicone	TiO_2	24	250
Butyl titanate						
-	Bu.tit.	None	Bu.tit.	Pol.Al.flake	24	250

Notes: Carbon arc. Radiation flux 4 cals/cm^2 per sec. giving a test panel temperature rise of rise of 13°C per sec.

N/C = Nitrocellulose
Pol.Al.flake = Polished aluminium flake pigment
U/F = Ureaformaldehyde
P/F = Phenol formaldehyde
Etch = Etch Primer, DTD.868
I.R. = Infra-red
S. = Scorching to a yellow colour
Bl. = Blistering
C. = Charring

4.4. The Mechanical Properties of Metals Heated for Short Periods

4.4.1. Introduction

In general the strength of metal falls with the rise of temperature. Over a range of 200°C, however, the fall may be modified and in the case of lowly alloyed steels even reversed, by an effect known as strain ageing or strain hardening, attributed to an incipient precipitation of impurity atoms within the crystal lattice impeding further slip. The temperature range over which this phenomenon occurs in steel is 200-400°C. Heat treatable alloys which rely for their strength on the formation or incipient precipitation of a metastable phase may lose both strength at temperature and residual room temperature strength rapidly when temperatures are reached at which local or metallurgical changes of structure occur quickly. With heat treatable aluminium alloys, these permanent changes occur at 200-250°C, depending on the type of alloy. The elastic stiffness (Youngs Modulus E) which is a property of each individual metal, and is substantially independent of the presence of alloying elements, falls steadily with rise of temperature. Recovery at room temperature is normally complete, if no changes of state have occurred.

The extent of thermal damage will depend both on the temperature and the time for which it is maintained. Very few results are available for brief heating, but an estimate of the effects may be based upon data for extended heat treatment. In most cases available data refer to room temperature measurements following heat treatment, but in some cases actual properties at the elevated temperatures are given. In many cases of military interest, it will be the actual time history of the strength of the material during heating that will be important. There are no such data available at present.

Sections 4.4.2. - 4.4.6. present typical data for the following properties:

(i) Tensile strength at temperature. In the case of unstable alloys which undergo permanent metallurgical changes at relatively low temperatures, the data are taken from short time tensile tests where these are available.

(ii) Young's Modulus at temperature.

(iii) Short time creep data at temperature. These are taken from U.S. Air Force Project Rand. (Reference 1).

(iv) Recovery properties at room temperature of unstable alloys.

A useful collection of papers on the behaviour of metals at elevated temperatures is presented in Reference (2).

In illustration of an extreme case of the problem, Figures 1A and 1B (taken from Reference (3)) give the material loss from spheres of various materials due to ablation or scaling off of the surface material from contact with or envelopment by the fireball. Data for three types of 10-inch diameter spheres are shown; namely, solid steel, solid aluminium, and solid aluminium with small cylindrical wells filled with ceramic inserts. The one curve in Figure 1A represents all three types.

References:

(1) Project Rand. Report R-147, U.S. Air Force, June, 1949.
Ministry of Supply Gas Turbine Collaboration Committee
R.C.301, 16831. (Restricted Discreet).

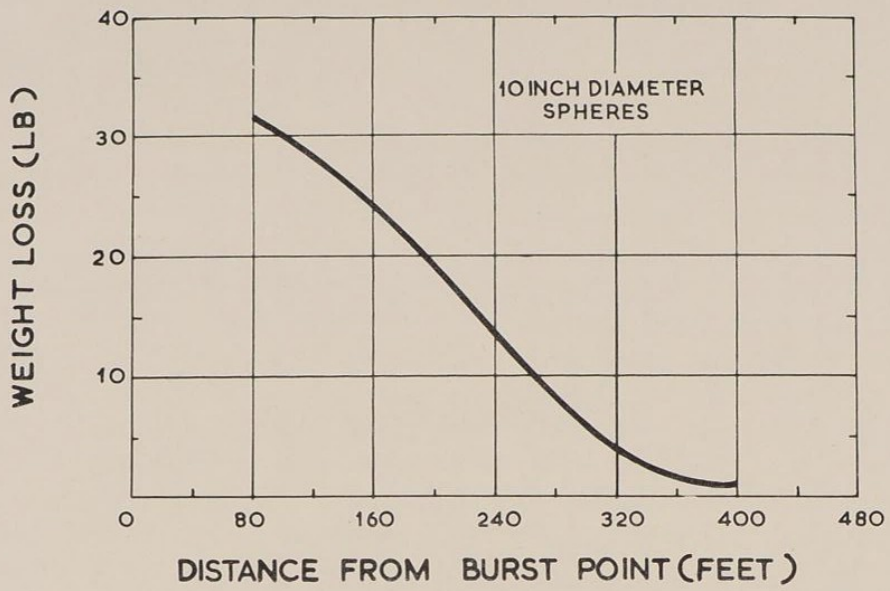
(2) Behaviour of Metals at Elevated Temperatures
- Institute of Metallurgists. (Iliffe & Sons, 1957)

(3) Capabilities of Atomic Weapons (1957)
U.S. Dept. of the Army, TM 23-200 (Confidential)

(4) High Temperature Effects in Aircraft Structures. N. J. Hoff
(Pergamon Press Ltd. 1958)

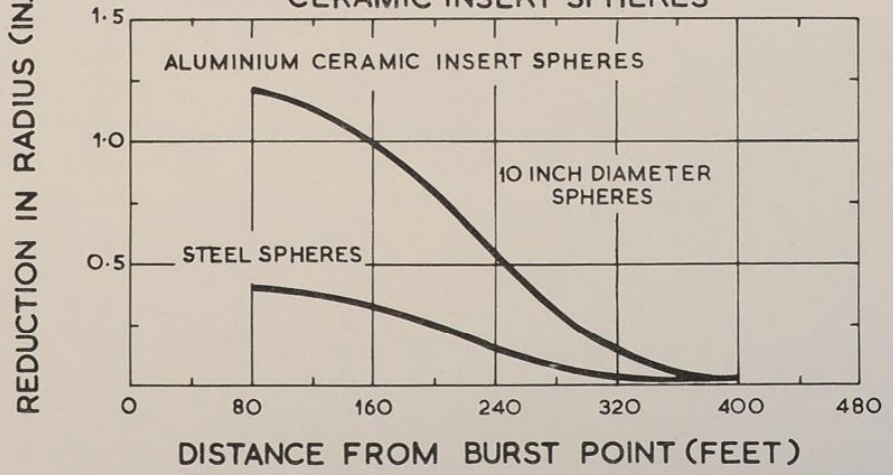
A.

WEIGHT LOSS WITH DISTANCE FROM A 23 KT BURST FOR ALUMINUM, STEEL, CERAMIC INSERT SPHERES

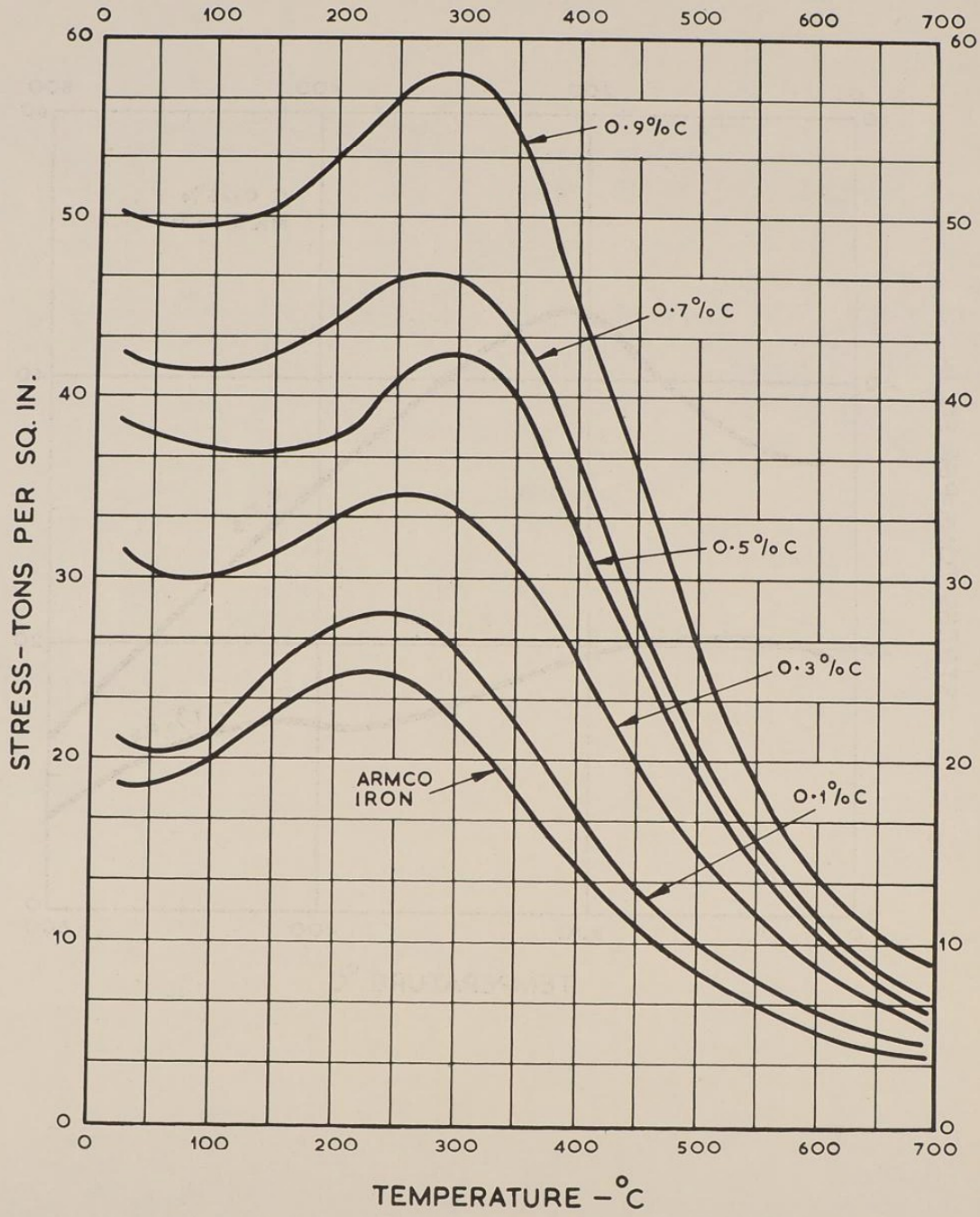


B.

REDUCTION OF SPHERE RADIUS WITH DISTANCE FROM A 23 KT BURST FOR ALUMINUM, STEEL, CERAMIC INSERT SPHERES



ABLATION OF METAL SPHERES BY THERMAL RADIATION



VARIATION OF ULTIMATE TENSILE STRENGTH WITH TEMPERATURE FOR A RANGE OF CARBON STEELS

PART VI
CHAPTER 4
SECTION 4.4.2
FIGURE 2

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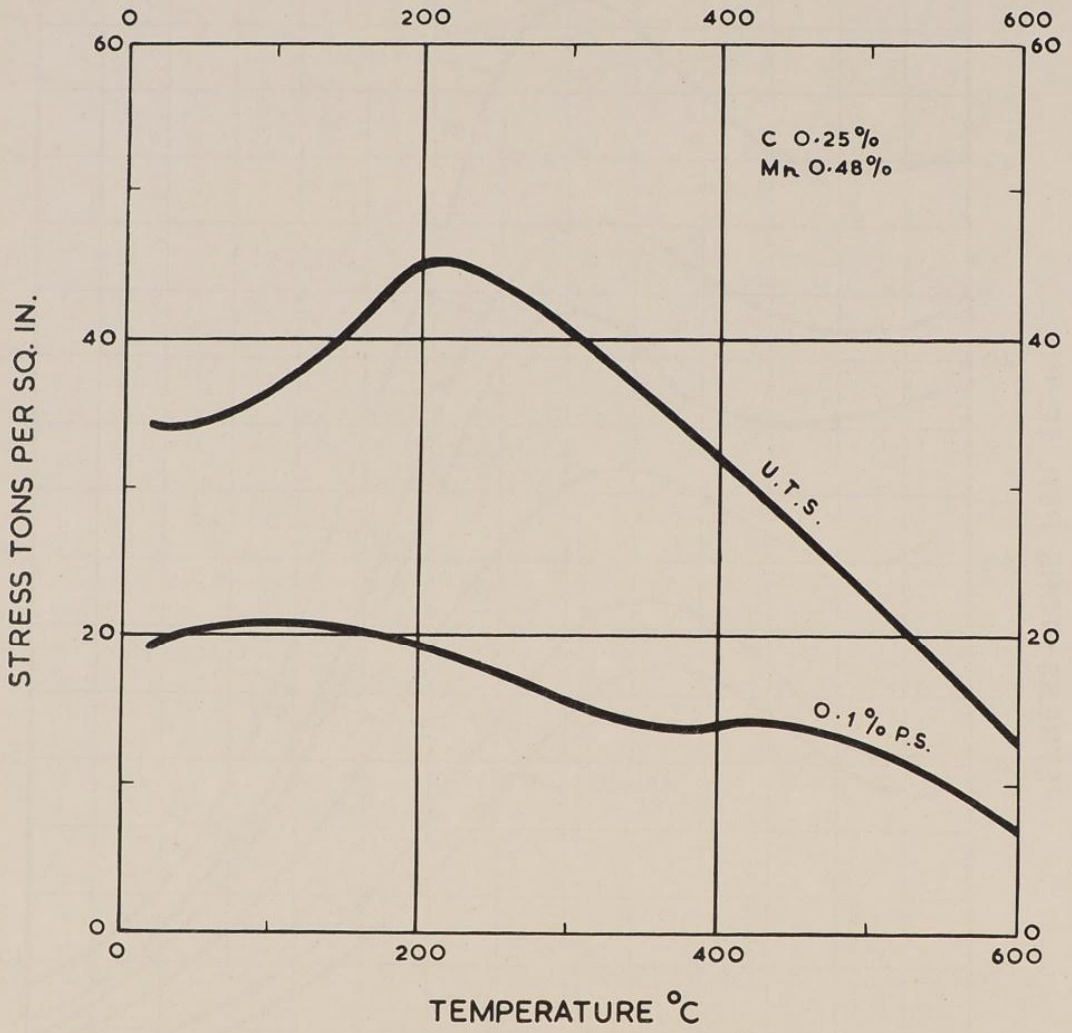

VARIATION OF STRENGTH OF MILD STEEL
WITH TEMPERATURE

4.5. Thermal Damage to Miscellaneous Service Equipment

4.5.1. Chemical Warfare Equipment

(a) Service respirators - The exposure of obsolescent respirators G.S. during Operation Totem (Reference (1)), showed that there was no increased hazard due to ignition of the rubber mask following a nuclear explosion, but that on the contrary, the mask gave a considerable measure of protection against facial burns. (See Section 4.2.1 for details.)

A further exposure trial during Operation Buffalo (Reference (2)) was intended to provide information on the new Service respirator (which is now in the final stages of Service trials and development), particularly with regard to the pneumatic periphery. It was also desired to obtain information on respirators within haversacks. Twelve respirators (Type D46/36) which were exposed on dummy heads to thermal doses from 2-96 cals/cm^2 behaved similarly to the respirators exposed at Operation Totem. They remained undamaged up to 8 cals/cm^2, and the majority would probably have been serviceable up to 12 cals/cm^2, in spite of surface melting of the external surface of the rubber. The internal surfaces, including the air bag, were not affected even at 32 cals/cm^2, and it is clear that external heat damage to the mask and head harness is the controlling factor from the respirator serviceability aspect. The new respirator is therefore no more vulnerable than the old respirator G.S., and owing to the pneumatic fitting would certainly give greater protection against heat, but this advantage would be offset by the increased exposure of the eye region through larger eyepieces.

Respirators in haversacks were unaffected up to 32 cals/cm^2, and at higher levels impact with surrounding objects as a result of blast is likely to be the factor controlling serviceability. The haversacks themselves showed slight discolouration at 6 cals/cm^2, but remained intact, although severely scorched at 32 cals/cm^2. At higher levels they were torn apart by blast, but were still not seriously affected by the heat.

It appears reasonable to conclude that worn respirators will remain serviceable under conditions in which the incidence of lethality for exposed men is high. (Cf. Chapter 7)

(b) Kits, Capour Detector - Of the six K.V.Ds exposed at Operation Buffalo, four were almost completely destroyed by burning, and were not returned to the U.K. for examination. Of the two returned, no particulars of the thermal dose received were known in one case, and the other kit was at a site which received 48 cals/cm^2. Of the two kits examined, the canvas carrying cases were badly scorched, the cotton seam had given way, and the strengthening plastic sheet had come out. Tests were carried out in the normal way for mustard gas and nerve gas vapour, with results normal for the K.V.D., showing in particular that the tablets had not been adversely affected by the heat.

(c) Detector Powder - Six tins of detector powder were exposed to various thermal doses with the following results:-

8-12 cals/cm^2 - slightly scorched
16-24 cals/cm^2 - scorched and dented
32-48 cals/cm^2 - blackened and badly dented at one side.

In all cases the powder had not been affected in any way and responded to tests for liquid contamination.

(d) Detector Paper - Boxes of detector paper pads were exposed at sites receiving heat doses of 8, 12, 16, 24 and 32 cals/cm^2. Though scorching and blackening had occurred on one side of the boxes, this was entirely superficial and had not affected the paper in any way. Response to liquid contamination was normal.

Some single sheets of paper were also exposed to thermal doses ranging from 2-128 cals/cm^2. Below 6 cals/cm^2 there was no visible effect; above this dose scorching and charring occurred progressively, until, at the highest doses the middle of the sheet was burnt out. In all cases reactions were obtained in tests for liquid contamination, though in some cases where the paper had been scorched badly, very fine contaminating drops might not be seen, particularly the yellow colour of the nerve gas test.

References

(1) A.W.R.E. Report No. T77/54, Operation Totem.
"Effects on Respirators Anti-Gas (Confidential)

(2) A.W.R.E. Report No. T28/58. Operation Buffalo,
Target Response Tests. Materials Group.
Part 9(a): Effects on Chemical Warfare Equipment (Confidential)

4.5.2. Aircraft Windscreens (Reference (1))

Three types of panels representing current practice in the construction of bullet-proof windscreens were exposed at a number of sites at Operation Buffalo to a 15-20 KT nuclear explosion. The types of panel chosen were:-

(a) bullet-proof panels 12" x 12" x 1.5", incorporating an annealed glass;

(b) front panels from a Vampire windscreen, length approximately 22 ins, width tapering from 12 ins. to 8 ins, thickness 2.2 ins.

(c) Hunter windscreen, length approximately 24 ins, width tapering from 13 ins. to 4 ins, thickness 1.5 ins.

The panels were exposed vertically in the metal frames, slightly above ground level, at sites which received thermal doses of 12, 16, 24, 32, 48 and 64 cals/cm^2 respectively.

Panels at the two nearest sites to ground zero were torn from their frames and thrown several yards, sustaining some impact damage. Frames at the remaining sites were buckled, but the panels were still in place. The exposure face was in all cases pitted by sand blasting, the degree of damage becoming progressively less with increased distance from ground zero. The light transmission had of course, been affected by this pitting, but it is doubtful if pitting would have occurred had the panels been exposed at the height and angle equivalent to their normal position in an aircraft. In no case had the Vinal interlayer been visibly affected by the thermal radiation. Detailed results are given in Table I.

TABLE I - Damage to Aircraft Windscreens at Operation Buffalo

Feet From GZ	Total Heat Dose cals/cm^2	Annealed Panel	Vampire Windscreen	Hunter Windscreen
1840	64	All glass layers cracked 1st layer 6 in. crack 2nd layer 3 in. crack 3rd layer 7 in. crack 4th layer 4 cracks max. length 6 in. Both exposed glass surfaces pitted	Broken in two. Rear face missing. All remaining glass layers heavily cracked. Some separation of inter-layer along cracks. Front face heavily pitted	Front and rear glass layers cracked. Front layer 5 cracks across width. Back layer three 1 in. cracks Front Face very heavily pitted
2070	48	Back two layers cracked. Rear 0.2 in layer three cracks maximum length 4 in. Rear 0.5 in. layer 4 in. crack. Front face pitted.	Rear face missing. Otherwise no cracks. Front face heavily pitted.	Front layer cracked, (7 in. length). Front face pitted.
2560	32	Back layer cracked (2 in. length). Front face pitted.	Rear face heavily cracked. Front face heavily pitted.	No cracks. Front face pitted.
2950	24	No cracks. Front face slightly pitted.	No cracks. Front face slightly pitted.	No cracks. Front face very slightly pitted.
3570	16	No cracks Front face slightly pitted	No cracks Front face slightly pitted	Back layer cracked (two 2 in. cracks) Front face very slightly pitted.
4050	12	No cracks Front face very slightly pitted.	No cracks. Front face very slightly pitted.	Front and back layers cracked at edge. Front layer 5 in. crack Back layer 1 in. crack No pitting.

It is concluded in Reference (1) that all three types of panel behaved very well. The impact damage (i.e. cracking and pitting) would probably not have occurred had the panels been exposed as part of aircraft, and in any case were at damage levels at which the aircraft themselves would have been rendered non-operational. The Vinal interlayer, although soon damaged by sustained exposure to comparatively low temperatures, was not affected even by the highest thermal flux to which it was subjected.

References

(1) A.W.R.E. Report No. T.28/58. Operation Buffalo Target Response Tests, Materials Group.
Part 9(c): Effects on Aircraft Windscreens.
(Confidential)

CHAPTER 5 - THERMAL DAMAGE TO VEGETATION

5.1. Types and Conditions of Vegetation

Under certain conditions, the employment of an air burst weapon over a forest or wild-land area, may cause fires. During the fire season*, even when the burning potential is low, fires may spread. Wild-land fuels are generally a mixture of thin and heavy fuel components. Thin fuels are typified by surface litter and grassland; heavy fuels by fallen branches. The thinnest fuel present determines the ignition energy for the mixture. Heavy fuels do not ignite and continue to burn by themselves, but thin fuels may serve as the source of a pilot flame and may spread fire after the end of the radiant pulse. The following information on types and conditions of vegetation has been obtained from Reference (1).

During the fire season, ignitions may be expected in kindling fuels where the total thermal energies exceed 2 - 3 cals/sq.cm. for a 1 KT weapon. As the yield increases, the minimum ignition energies increase as $W^{\frac{1}{8}}$, i.e. 8-10 cals/sq.cm. would be required from a 30 MT weapon to ignite the thinnest wild-land fuels.

It is estimated that very few ignitions will occur within a forest in which the tree canopy shades more than 20% of the ground surface. Green leaves on tree crowns smoke and char, but do not normally sustain ignition.

Table 1 summarises the conditions which exist in forest and heath areas etc., during the fire season; the latter varies in different locations according to temperature and rainfall.

* For definition see Table 1.

TABLE I

The Condition of Wild land Fuels During Fire Season

Fuel Type	Description	Amount and Density of fuel to constitute a fire hazard	Condition During Fire Season
Grass or heath	Grassland, dry bracken, ferns, seasonal plants	Uniform grass cover $\frac{1}{2}$ ton or more per acre	Vegetation nearly dry or dead
Evergreen bush	Perennial evergreen shrubs and brush	75% or more area covered	15-25% by weight of leaves and twigs dead
Deciduous forest	Forest predominantly of broad-leaf trees, leaves of which die and fall each year	Ground covered with more or less continuous layer of dead leaves	Leaves off trees. Ground vegetation dead or non-existent
Coniferous forest	Forests of evengreen pines - needle bearing trees	Ground covered with a more or less continuous layer of dead needles and twigs	Needles and twigs dry enough to break easily when bent. Grass and other vegetation present dry or dead.

The majority of thin wild-land fuels which serve as kindling material are divided, in Table 2, into four classes corresponding to different minimum ignition energy levels. Ignition energies increase as fuel moisture content increases. Since ignition generally occurs on those surfaces most exposed to the atmosphere, ignition energies are a function of relative humidity, as shown in Figure 1.

TABLE 2

Classes of Thin Wildland Kindling Fuels (in order of flammability)

Class	Description
I.	Broadleaf and coniferous litter; mixture of fine grass, broken leaves and thin translucent broadleaf leaves.
II.	Hardwood and soft wood in various stages of fungoid decay.
III.	Dried or dead grass.
IV.	Conifer needles and thick, nearly opaque broadleaf leaves.

Fires may be blown out by blast depending on the time interval between ignition and arrival of the shock. Blowout is not expected in regions below 5 p.s.i. for fully exposed fuels. If the fuel is in a hole or pocket, the chance of blowout is materially decreased. When fires are not blown out, they generally increase in intensity owing to the action of the blast wind.

The principal factors, apart from the fuels present, that influence the burning potential of forest or wild-land areas, are the nature of the terrain, the wind speed close to the ground, the relative humidity, and the precipitation history. An approximate guide for evaluating the effects of weather or burning potential is given in Table 3. Fuels seldom burn vigorously, regardless of wind conditions when the fuel moisture is greater than 16 percent. This corresponds to an equilibrium moisture content for 80 percent relative humidity. About a quarter of an inch of rain renders fuels temporarily non-inflammable, and may extinguish going fires in thin fuels. The time required to restore the burning potential may vary from hours to days depending on local weather conditions. Surface fuels in the interior of forests are exposed to reduced wind velocities and generally have high fuel moistures due to shading by the canopy.

Table 3 - Burning Potential for Light Wildland Fuels During Fire Season (Terrains with slopes less than 20 percent)

Wind Speed 20 ft. above ground in the open	Relative Humidity (percent)			
	Below 15	15 - 40	40 - 65	65 - 80
Below 5 knots	Dangerous	Dangerous	Low	Low
5 - 10 knots	Critical	Dangerous	Dangerous	Low
10 - 15 knots	Critical	Critical	Dangerous	Low
Above 15 knots	Critical	Critical	Critical	Dangerous

Definitions (for Table 3)

Low - irregular fire perimeter, spread greatly affected by changes in fuel structure and topography, depth of fire small. Fire generally stops at roads and ridge-tops. Control action can be on an individual basis.

Dangerous - continuous intense fire front which moves rapidly. Frequently spots ahead. Aggressive organised action required to protect personnel and equipment.

Critical - conflagration-type fire, in heavy fuels readily crowns and spots as much as a mile ahead. Control action only when changes in fuel type or burning conditions permit.

Notes (a) For heavy fuels, use the classification for next higher wind speed.

(b) For terrain with slopes greater than 20 percent, use the classification for the next higher wind speed.

(c) For canopy shading 20 percent of the ground, reduce wind one class, and increase relative humidity one class.

(d) For full shading, reduce wind two classes and increase relative humidity two classes.

Details of damage to forests by airblast are given in Part III, Chapter 9, Section 9.9.

References.

(1) Capabilities of Atomic Weapons, (1957) U.S. Dept. of the Army TM 23-200. p.11-2. (Confidential)

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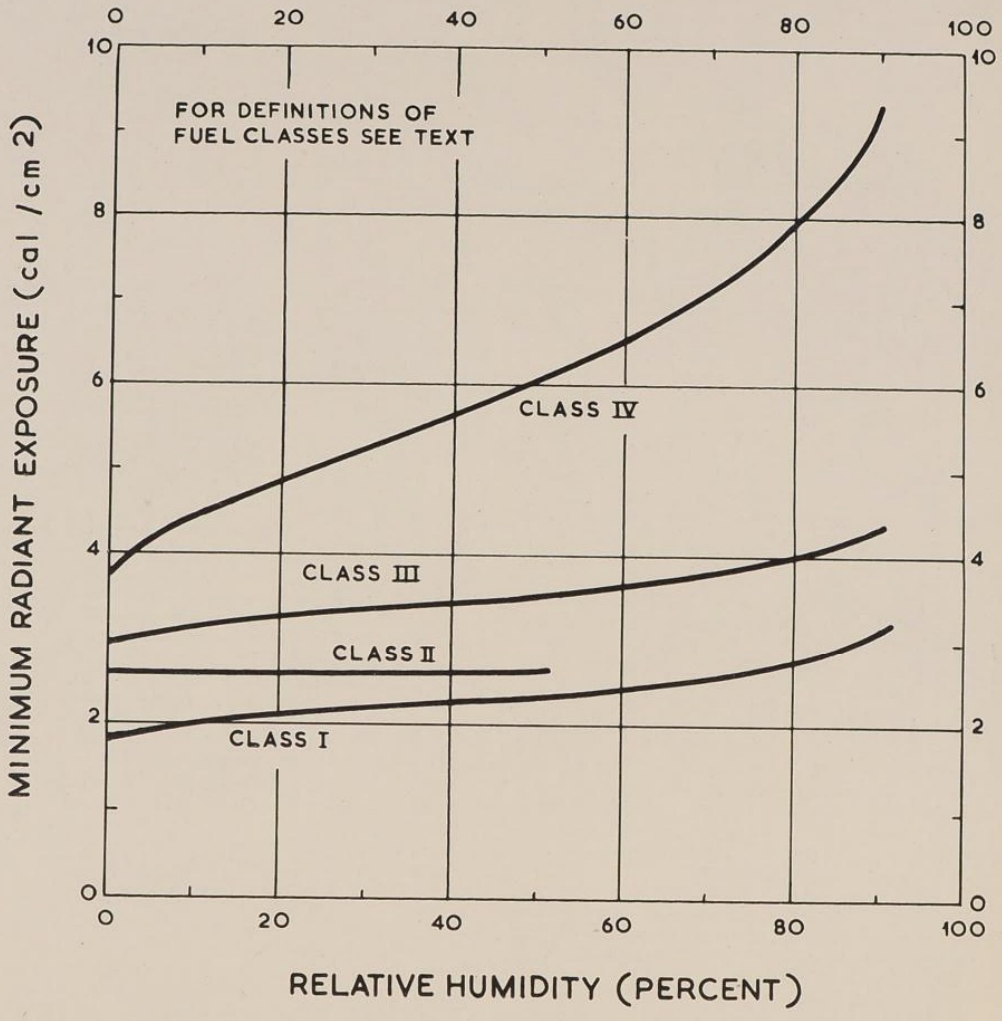
PART VI
CHAPTER 5
SECTION 5.1
FIGURE 1



MINIMUM RADIANT EXPOSURE FOR IGNITION OF WILDLAND KINDLING FUELS- SCALED TO 1KT

CONFIDENTIAL

5.2. The Results of Atomic Weapon Tests on Forest Fuels

During the U.S. Atomic Weapon Test "Operation Snapper", measurements were made of the minimum thermal energies required to ignite common forest fuels, (Reference (1)). Observations were also made to determine blast wave effects on the persistence of ignition and to provide field data against which laboratory source tests could be scaled.

Prepared fuel beds of conifer needles, hardwood leaves, grasses and rotton wood, were exposed in Operation Snapper to total thermal energies varying from 1 - 22 cals/sq.cm. Thickness and density of fuel particles were determined prior to the test. Fuel moisture at shot time was measured in duplicate field beds, similarly located, but outside the test area.

Post test fuel examinations showed that decayed materials and fine grasses ignited and continued to burn at distances from Ground Zero where the total thermal energy was approximately 3 cals/sq.cm. Following shots 3 and 4, decayed materials were still burning upon recovery at H + 2 hours. The following conclusions were made ffom the test results.

(i) Under fire-weather conditions (relative humidity less than 40%, air temperature greater than 35°F, fuel moisture less than 15%) in a forest area, atomic explosiions can be expected to ignite decayed and fine grassy fuels wherever the total thermal energy exceeds 3 cals/sq.cm.

(ii) Minimum ignition energies have been established towithin approximately ± 10% for common wild-land fuels - pine needles, hardwood leaves, grasses and rotted materials.

(iii) Rotted or decayed materials and fine grasses which are ignited at low energy levels by atomic explosions, can spread fire to associated fuels which would not otherwise have been ignited.

(iv) Sparse tree crowns exposed to energies of 22 cals/sq.cm. effectively shade dead surface fuels so that few ignitions of these fuels can occur in their shadow. Dense green forest stands, with 100% crown closure, should offer few, if any, ignition points where persistent ignition and fire would occur.

References

(1) Operation Snapper, Project S .1. The Effect of Atomic Explosions on Forest Fuels. WT-506, AFSWP. (Confidential)

Part VI
Chapter 5
Section 5.3

D1/57
November, 1958

5.3. Estimated Effects of Atomic Weapons on Forests of N.W. Europe

An assessment has been made (Reference (1)) of the general effects of exploding atomic weapons over forests, with particular reference to blast and fire hazards. The degree of protection likely to be afforded by forests in N.W. Europe to stores, vehicles and personnel in them, has been examined, and also the possibility of exploding atomic weapons over forests in order to create obstacles to the movement of tracked and wheeled vehicles and personnel, has been assessed. Two areas in which obstacle belts might be created in forests were examined in detail; the area to the S.W. of Kassel, and the area between Uelzen, Gifhorn, and the Eastern Frontier.

The main conclusions reached in the Paper were:-

(i) The range for ignition of forest fuels by thermal radiation from atomic weapons will exceed the range of blast damage under fine weather conditions, but when the weather is not fine, blast damage becomes of major importance.

(ii) The probability of fires started by the ignition of forest fuels spreading and leading to a general conflagration is small at all seasons of the year in W. Europe, but limited danger periods may exist during spells of dry weather, especially in the spring and autumn.

(iii) Forests can provide useful protection against the thermal effects of atomic weapons, the amount of thermal shielding being proportional to the projected area of foliage between the weapon and the target. All the year round protection is available in the coniferous forests which make up 70% of the total in Germany, the deciduous forests can only provide thermal shielding when in leaf.

(iv) Forests provide little in the way of blast protection to man and material in them. Rather, falling trees and branches and other secondary blast effects may hurt or damage men and equipment at ranges where they would be unaffected in the open and may also prevent access to stores or equipments in woods attacked by atomic weapons until such time as a major clearance effort can be made. (See Part III, Chapter 9, Section 9.9 for details of blast damage to forests).

Reference

(1) The Effects of Atomic Weapons on Forests in N.W. Europe.
Operational Research Section, B.A.O.R. Report 3/56 (Confidential)

D1/57
Nov. 1958

CHAPTER 6 - THERMAL DAMAGE TO BUILDINGS AND URBAN AREAS

6.1 Origin of Fires

There are two general ways in which fires can originate from a nuclear explosion. Firstly, by the ignition of paper, rubbish, window curtains, awnings, dry grass and leaves etc., as a direct result of the absorption of thermal radiation. And secondly, as an indirect effect of the destruction caused by the blast wave, fires can be started by upset stoves and furnaces, electrical short circuits and broken gas pipes. No matter how the fire originates, its subsequent spread will be determined by the amount and distribution of combustible materials in the vicinity. It will be seen therefore, that the development of fires accompanying a nuclear explosion depends on two factors; firstly, the number of points at which fire originates, and secondly, the character of the surrounding area.

A study of the mechanism of initiation and development of fires from a nominal (20KT) atomic bomb is made in Reference (1). It is concluded that primary fires were much more numerous than secondary fires after the atomic weapon bursts in Japan, and that a large number of primary fires would probably result from an atomic burst over a British city. The simple precaution of preventing the entry of heat flash through window openings would greatly reduce the risk of primary fires from an atomic bomb. The Hiroshima fire storm must therefore have been due to primary fires. Normal scaling of the figures given in Reference (1) suggests that the fire zone could extend beyond the blast damage zone in the case of megaton weapons burst over cities.

Reference (1) also examines the incidence of secondary fires from H.E. bombs in the United Kingdom and in Japan, and a detailed account of secondary fires from the fly bomb attack on London in 1944 is given. From this evidence it is deduced that one nominal atomic bomb on a British city would probably start about 300 large secondary fires requiring the attention of the Fire Service, and about 1,000 small debris fires which could easily be extinguished by fire guards, if they did not go out of their own accord. This is not a serious fire situation, and could hardly give rise to a fire storm comparable with that at Hiroshima (see Section 6.2.2 of this Chapter), since this would require about 10,000 large initial fires in the damage area.

The fact that accumulations of combustible rubbish close to a wooden structure represent a real fire hazard was demonstrated at the nuclear tests carried out in Nevada in 1953. In these tests, three miniature wooden houses each having a yard enclosed with a wooden fence, were exposed to 12 cals/sq.cm. of thermal radiation from a weapon of about 30KT. The first house had weathered siding showing considerable decay, but the yard was free from rubbish. The second house also had a clean yard, and further, the exterior siding was well maintained and painted. In the third house the siding, which was poorly maintained, was weathered, and the yard was littered with rubbish. Following the explosion, the third house soon burst into flame and was burnt to the ground. The first house did ignite but it did not burst into flame for 15 minutes. The well-maintained house with the clean yard suffered scorching only. It was also noted that the wood of a newly erected white-painted house exposed to about 25 cals/sq.cm. was badly charred but did not ignite, (Reference (2)).

The incidence of wooden houses is very small in the United Kingdom and so the possibility of ignition from the outside is not nearly so great as in

this American test. However the test also showed that the radiation entering through windows caused combustion inside the houses, and this was sustained in the case where much combustible material was lying about, but died out in a tidy room with a low combustible content.

Critical energy data for various combustible materials are given in Section 4.2, Chapter 4, and some further values, given in Table 1 below, are taken from p.307 of Reference (3).

Table 1

Thermal Energies for the Ignition of Household Materials

Material	Weight (oz/sq.yd.)	Ignition Energy (cal/sq.cm.)	
		20 kilotons	10 megatons
Dust mop (Oily, grey)	-	3	5
Newspaper, shredded	2	2	4
Paper, crepe (green)	1	4	8
Newspaper, single sheet	2	3	6
Newspapers piled flat, surface exposed	-	3	6
Newspapers, weathered, crumpled	1	3	6
Newspaper, crumpled	2	4	8
Cotton waste (oily, grey)	-	5	8
Paper, bond typing, new (white)	2	15	30
Paper, Kraft, single sheet (tan)	2	7	14
Matches, paper book, blue heads exposed	-	5	9
Cotton string scrubbing mop, used (grey)	-	6	10
Cellulose sponge, new (pink)	39	6	10
Cotton string mop, weathered (cream)	-	7	13
Paper bristol board, 3 ply (dark)	10	8	15
Paper bristol board, 3 ply (white)	10	12	25
Kraft paper carton, flat side, used (brown)	16	8	15
Kraft paper carton, corrugated edges exposed, used (brown)	-	12	25
Straw broom (yellow)	-	8	17
Excelsior, Ponderosa pine (light yellow)	2 lb/cu.ft.	5	12
Tampico fibre scrub brush, used (dirty yellow)	-	10	20
Palmetto fibre scrub brush, used (rust)	-	12	25
Twisted paper, auto seat cover, used (multicolor)	13	12	25
Leather, thin (brown)	6	*15	*30
Vinyl plastic auto seat cover	10	*16	*27
Woven straw, old (yellow)	13	*16	*33

*Indicates material was not ignited to sustained burning by the incident thermal energy indicated.

Since thin kindling materials quickly reach equilibrium with the moisture condition of the atmosphere, the relative humidity has a marked effect on the critical ignition energy of any such fuels. Under conditions of high humidity, the ignition energy may be increased by 30 to 50 per cent.

There is another point in connection with the initiation of fires by thermal radiation which needs consideration. This is the possibility that the flame resulting from the ignition of a combustible material may be subsequently extinguished by the blast wind. It was thought that there was evidence for such an effect from an observation made in Japan, but this may have been an exceptional case. The matter has been studied both in connection with the effects in Japan, and at various nuclear tests, and the general conclusion is that the blast wind has no significant effect in extinguishing fires. (Reference (3), p. 319).

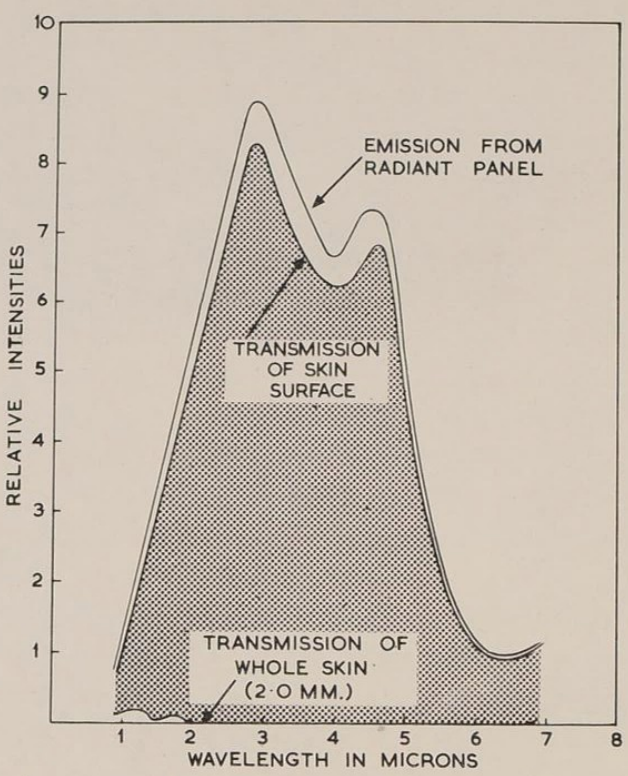
References

(1) Home Office Report CD/SA 6 - "The Atomic Bomb as a Fire Raiser - a Study of the Mechanism of Initiation and Development". (Secret).

(2) U.S. Civil Defence Administration Film,

"The House in the Middle".
(Home Office Film Library).

(3) The Effects of Nuclear Weapons, U.S.A.E.C., 1957.



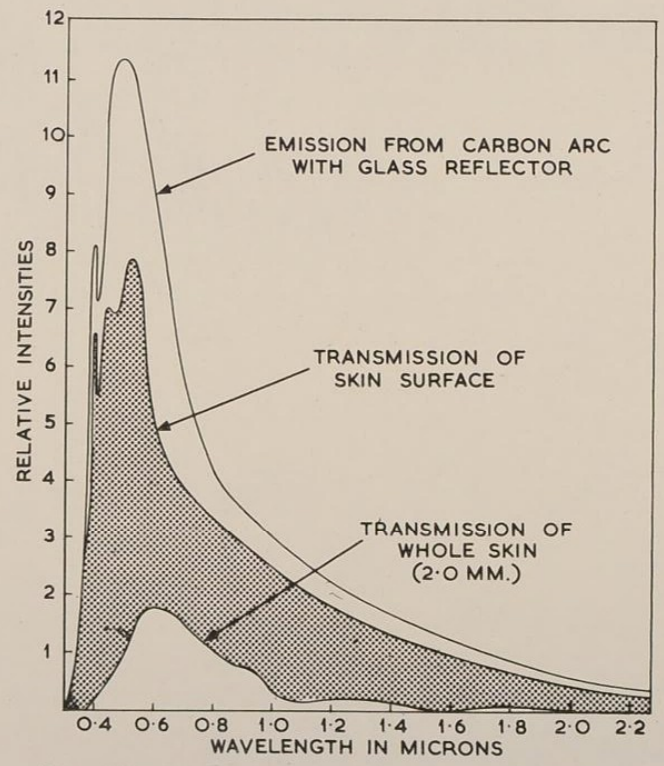
A. TRANSMISSION OF SKIN SURFACE BY INFRA RED RADIATION

FIGURES A AND B SHOW :-

1. SPECTRAL DISTRIBUTION OF RADIATION FALLING ON THE SKIN FROM:-
   A. INFRA RED SOURCE
   B. WHITE LIGHT SOURCE
2. TRANSMISSION OF THE SKIN SURFACE.
3. PENETRATION BEYOND 2 MM. DEPTH INTO SKIN.

THE AREA BETWEEN TOP AND MIDDLE CURVES OF EACH FIGURE REPRESENTS SKIN REFLECTION.

THE SHADED AREA REPRESENTS ABSORPTION IN THE SKIN, FROM SURFACE TO 2 MM. DEPTH.



B. TRANSMISSION OF SKIN SURFACE BY RADIATION FROM PREDOMINANTLY WHITE LIGHT SOURCE

7.4 Healing Times of Uninfected Flash Burns

The information about threshold doses for flash burns given in Section 7.3. provides data for predicting for Civil Defence or military purposes the ranges of flash burns and the areas wherein they may be sustained (see Section 7.5). Another important factor in this connection is the duration of incapacitation to be expected if complications, especially infection, are prevented. This factor has been investigated methodically in the case of flash burns from predominantly white light (Method (ii) Section 7.3.2), between the limits of doses of 2.0 to 5.25 cals/cm^2. Above 5.25 cals/cm^2, the healing time will be affected by the surgical resources available to treat the 3rd degree burns caused. All the experimental flash burns were kept free from infection by suitable cleansing shortly after burning and by antibiotic barrier creams and occlusive dressings, and the course followed until they were accepted as healed by five qualified observers. The criteria for healing were absence of soreness to touch or firm healing of the skin over the burn. Soreness tended to outlast firm healing in shallower burns but it was taken as a criterion because flash burns are likely to affect the hands, and soreness there would incapacitate casualties.

The relationship between the dose of incident energy per sq.cm. and the healing time for the complete series of 1 cm. diameter flash burns from predominantly white light (unfiltered beam from carbon arc.), was:

$$t = 0.92\, q^2 + 1.26q - 4.26$$

where t = healing time in days

and q = dose in cals/cm^2.

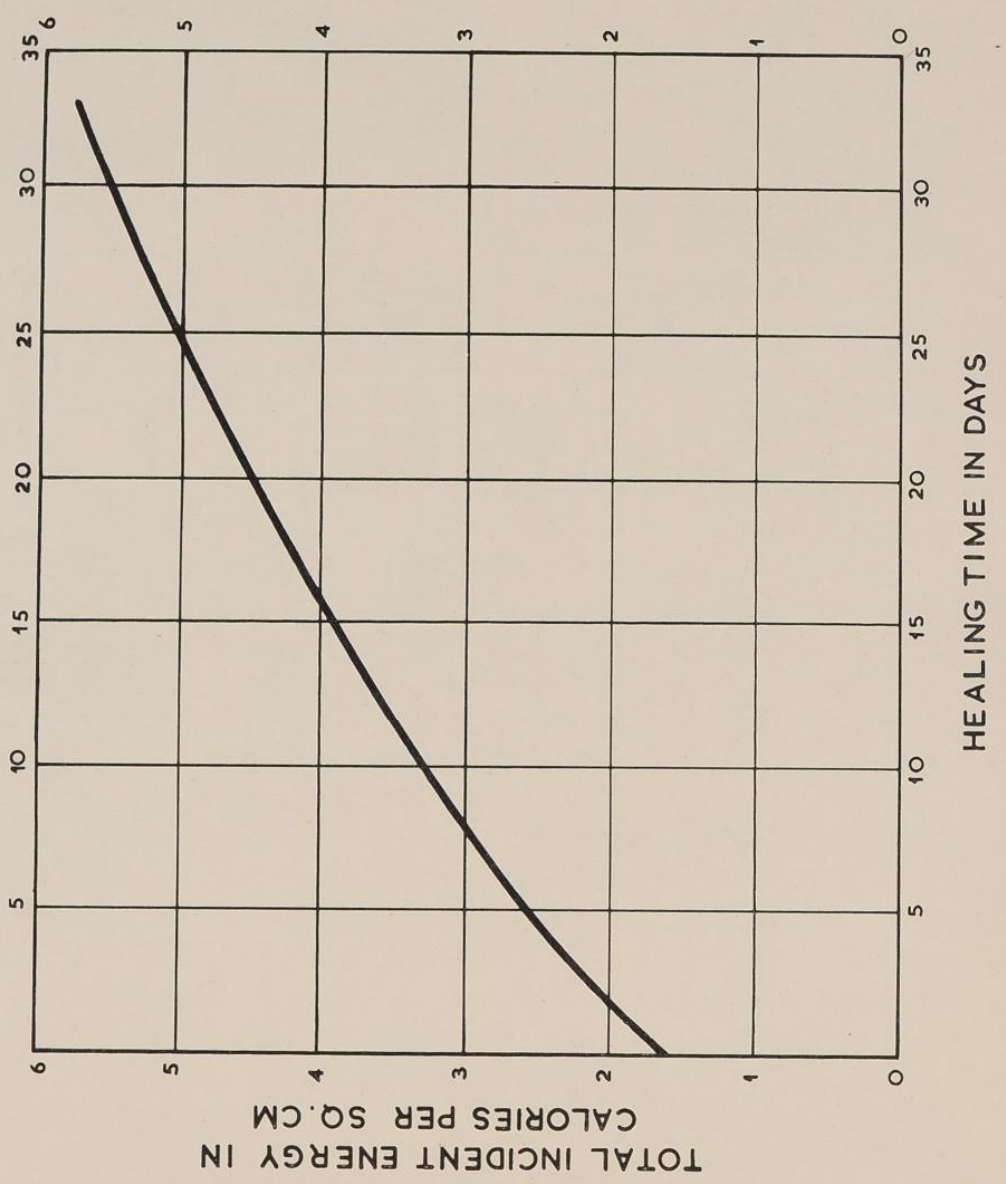
It may be noted that t becomes finite when q exceeds 1.5 cals/cm^2. When allowance is made for the area dependance of 1st degree flash burns, that the threshold is less if larger areas are exposed, it is apparent that the disability caused by 2.0 cals/cm^2 falling on the face or hand would be significant even if not warranting special medical dressings, etc. This relationship is given in graphical form in Figure 1 (from Reference (1)).

From the formula, the healing time to be expected for uninfected flash burns from 3.0, 4.0, and 5.0 cals/cm^2 of predominantly white light would be 8, 15 and 25 days respectively. These healing times would be extended by infection, which destroys the surviving skin cells thereby producing, in effect, a deeper burn. Thus, in another experiment, No. (i), Section 7.3.2, although uninfected burns healed in 12-24 days, one which was inadvertently infected required 42 days to heal.

Healing times were not studied systematically in the other investigations involving volunteers, but the qualitative statements given about healing times are in good agreement with the formula.

Reference

(1) Tripartite Conference on Effects of Atomic Weapons (1957). Paper AWEC/P(57)104 (Confidential). "Flash Burns from Atomic Weapons" by W. J. H. Butterfield and E. R. Drake-Seager.



HEALING TIME OF UNINFECTED
WHITE LIGHT FLASH BURNS
KILOTON WEAPONS

7.5. Casualty estimation

7.5.1 Flash burns

The hazard of flashburning can be estimated by calculating the threshold doses and healing times from the thermal doses received from surface of air burst atomic weapons.

The range of flash burning will increase with increasing weapon yield, and decrease with increasing atmospheric attenuation. The experimental results given in Section 7.3.2 should provide reliable data for weapons of yield up to 100 kilotons. The ranges so calculated can then be compared with those for gamma radiation injury and injury from the effects of the blast wave.

The importance of flashburning in a community can be judged best by considering the areas in which burns of various severities may arise, and by comparing these areas to those wherein other injuries may be sustained, always remembering that flashburning affects only those exposed directly to the heat flash, unshielded by buildings etc., which is by no means true of gamma and blast injuries.

The solutions to this problem for a 20 KT bomb exploded at a height of 2,000 ft. in weather with attenuation equivalent to a visibility of $12\frac{1}{2}$ miles have been calculated and are presented in Table 1 below.

Table 1

Range and Area of Injury from Specified Effects

Cause of injury	Range of injury (yards)	Area of injury (Square miles)
Gamma radiation (150r)	1,450	2.1
Blast (2.7 p.s.i.)*	3,000	9.0
3rd degree flash burns (5.0 cals/cm^2)	3,200	10
2nd degree flash burns (3.0 cals/cm^2)	4,000	16
1st degree flash burns (2.0 cals/cm^2)	4,800	23

*This range depends on whether the population takes effective cover between the flash and the arrival of the blast wave. The estimate quoted is based on Japanese experience.

All things considered, the findings in Table 1 agreed well with the events observed in Japan.

The relationship between the range of risk of flash burns and weapon yield is given graphically in Figure 1. The ground area of the annulus for risk of flash burns is a function of weapon yield as given in Figure 2. Figure 3 gives an estimate of the relationship between weapon yield and minimum manpower loss for flash burns severe enough to demand medical attention. All three Figures are taken from Reference (1).

Some figures for the percentage of non-effectives among military personnel who receive second and third degree burns have been obtained from Reference (2), and are presented in Table 2. It should be emphasised that the data in Table 2 do not indicate the percentage of target population which becomes non-effective, but refer only to the percentage of non-effectives among those personnel who actually receive burns.

Table 2

Percentage of Non-Effectives* Among Military Personnel Who Receive 2nd and 3rd Degree Burns, as a Function of Time after Detonation

Hours after Detonation	Degree Area around both eyes burned		Degree Back of one hand burned		Degree 15% total body burned	
	2nd	3rd	2nd	3rd	2nd	3rd
0.5	10	50	8	60	10	50
1	20	100	10	30	0	55
2	40	100	30	30	0	55
3	50	100	40	30	0	55
4	60	100	50	30	5	60
5	80	100	50	40	30	80
6	100	100	50	50	50	90
24	100	100	100	100	80	100

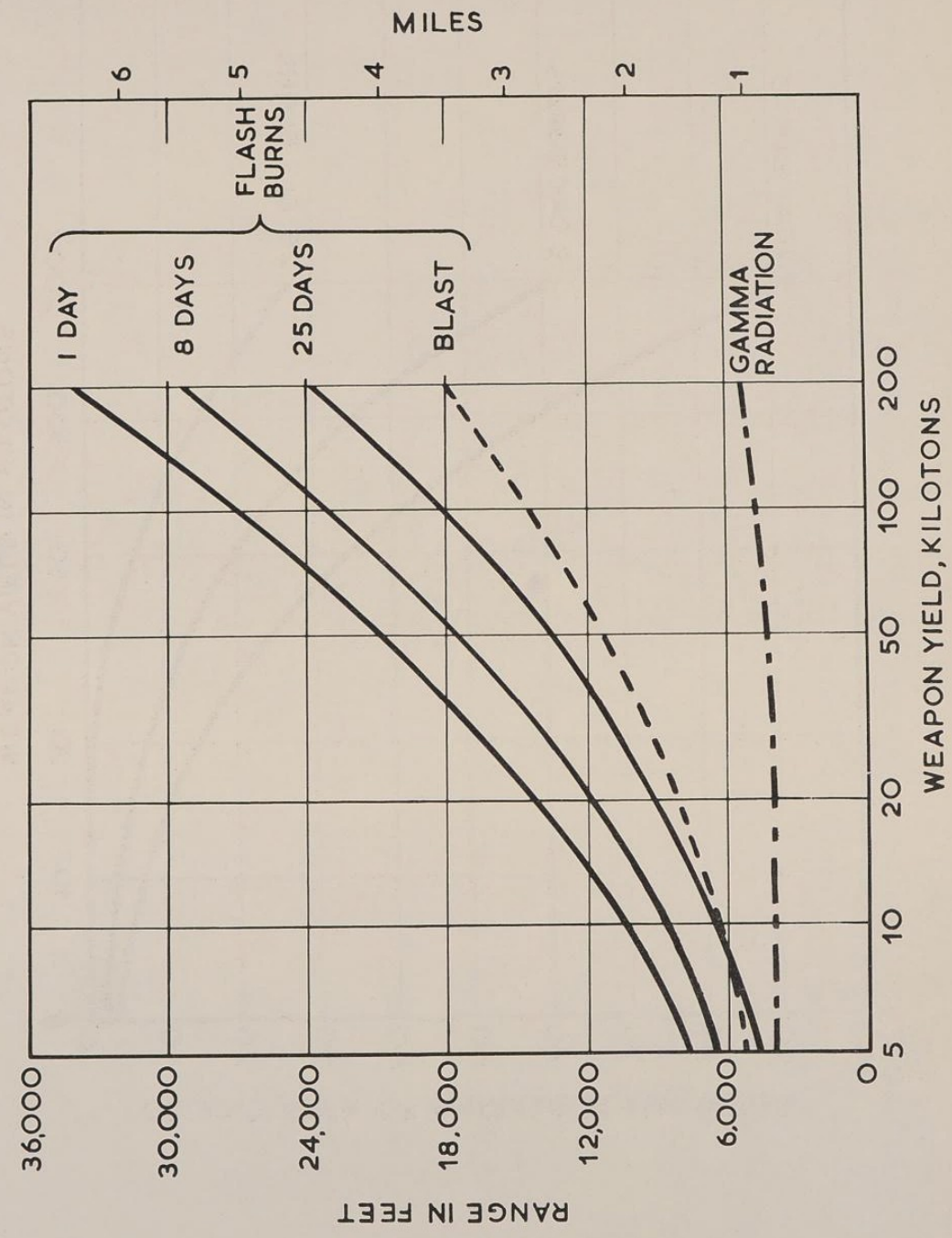
*Note: A Non-Effective (or Combat ineffective) is defined as a person who, because of his injuries, is no longer capable of carrying out his assigned tasks. This is differentiated from the more common term "casualty" which means an individual whose injuries require medical attention.

References.

(1) Tripartite Conference on the Effects of Atomic Weapons (1957) Paper AWEC/P(57) 104 "Flash burns from atomic weapons" by W. J. H. Butterfield and E. R. Drake Seager (Confidential).

(2) Staff Officers' Field Manual - Atomic weapons employment. U.S. Dept. of the Army FM 101-31 (Secret Atomic).

PART VI
CHAPTER 7
SECTION 7.5.1
FIGURE 1



RELATIONSHIP BETWEEN RANGE OF RISK
OF FLASH BURNS AND WEAPON YIELD

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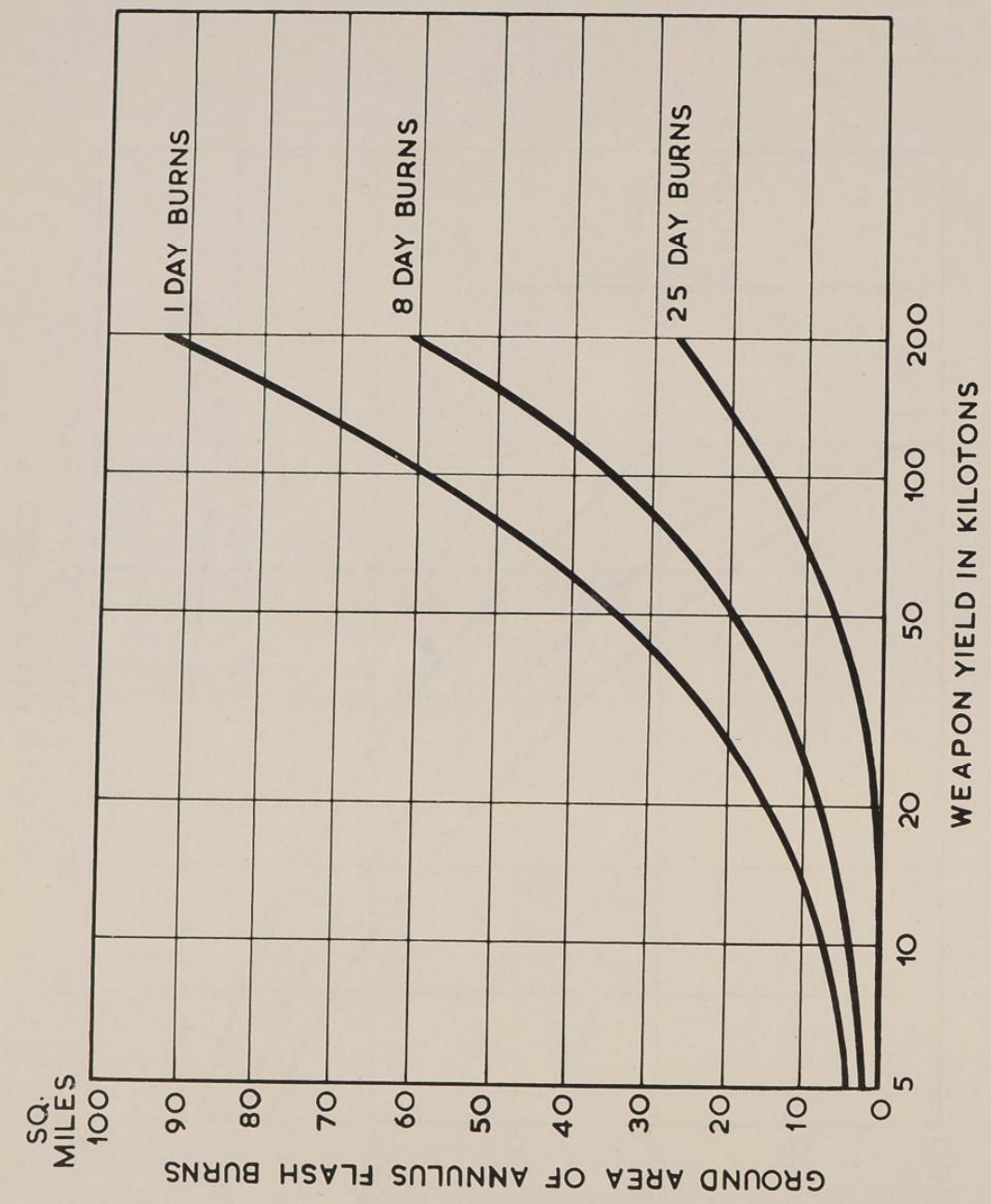
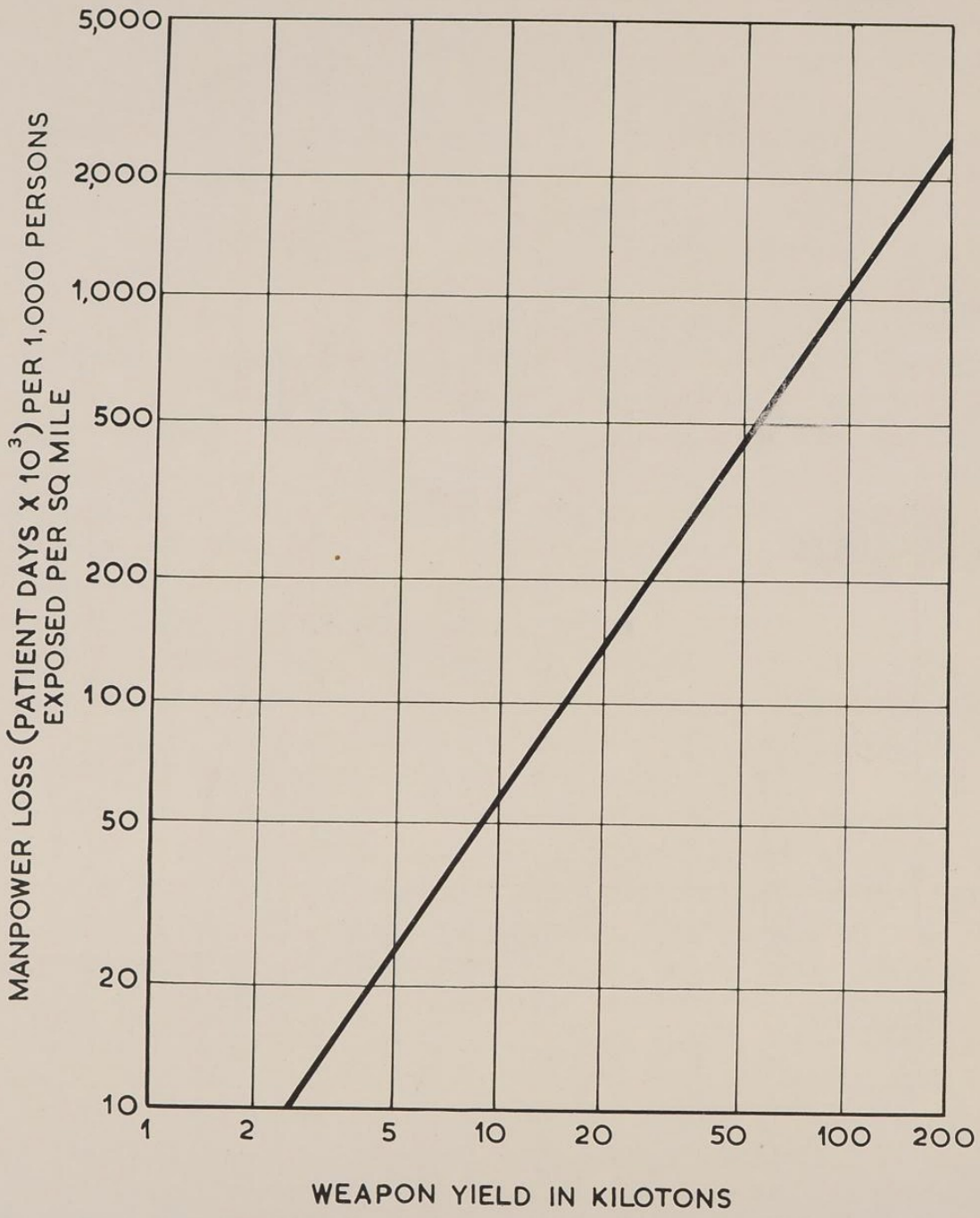


RELATIONSHIP BETWEEN GROUND AREA OF ANNULUS
FOR RISK OF UNCOMPLICATED FLASH BURNS
AND WEAPON YIELD



MANPOWER LOSS FROM FLASH BURNS AS
A FUNCTION OF WEAPON YIELD

7.5.2 Atmospheric Attenuation

In considering the effect of atmospheric attenuation on the range of flash-burning, it must be pointed out that atomic weapon tests have been conducted in remote places in good weather. It was assumed that the transmission of radiant heat under these circumstances would be good. It was further assumed that the transmission of radiant heat would be attenuated by the atmosphere in bad weather, with consequent shortening of the ranges of thermal effects. To calculate ranges in poor weather it was suggested that the transmission of thermal radiation be related directly to visibility. But visibility takes no account of infra-red transmission, nor does it allow for radiation scatter. Thus, while there is little doubt that rain or fog would severely curtail the transmission of the thermal radiation from an air burst weapon, there is evidence that the interaction of attenuation and scatter over the whole spectrum may mean that in dry weather transmission would, in effect, be roughly comparable to that previously quoted for a visibility of $12\frac{1}{2}$ miles, irrespective of the visibility appreciated by the human eye. (See also Chapter 1, Section 1.2.2).

7.5.3 Scaling Laws

The influence of weapon yield on the range, ground area and healing times of flash burns can be worked out by making calculations similar to those shown in Section 7.5.1 for different circumstances up to the limit of 100 KT bombs.

For larger weapons, the considerations become more complex. The duration of the flash becomes an important factor. The range of flash-burning cannot be estimated accurately until it is decided what period of time from the start of the flash should be allowed for casualties to take evasive action. Anyone who has volunteered for flash-burning experiments or focussed a burning glass upon his skin will know the quickness of the response to the painful stimulus of intense radiant heat. Although the physical measurements at trial explosions indicate that 70% of the total radiant heat from a 20 KT weapon is released in 0.5 seconds, the biological evidence from the Japanese survivors and subsequent animal experiments at weapon trials suggest that physiological responses, flash burns, were inflicted in a briefer period. Remarkable shadow effects were observed among the Japanese casualties moving at the moment of detonation. This discrepancy between biological effect and physical measurement has not been adequately explained.

It would seem unlikely that the population attacked would remain stationary for exposures of over 1.0 seconds while sustaining burns: they might not suffer pain during the first half of the exposure, but experience indicates that they would not keep still for the next half second after feeling stinging pain. If the flash continues for a longer period, the motion of the population trying to evade painful burning could bring them to expose again the area originally facing the fireball. Thus, although there has been considerable study of the change of threshold dose for 2nd degree flash burns of anaesthetised pigs for exposure times from 0.3 to 30 seconds, the formula derived* is hardly applicable to conscious man.

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* $Q_c = 3.73 t^{0.224}$ where Q_c = Heat dose (total) cals/cm^2 and

t = time in seconds. See Reference (3) data sheet 6a.2.

Again, it has been shown that 4.8 cals/cm^2 given as a pulse simulating the heat flash from a 20-kiloton weapon and lasting 0.54 seconds, caused a 2nd to 3rd degree flash burn, whereas a pulse lasting 2.2 seconds caused a superficial 2nd degree flash burn, and a pulse lasting 3.4 seconds caused only a 1st degree flash burn in man. However, before assuming that an extension of the duration of the heat flash by a factor of nearly 7 (0.54 to 3.4 seconds) would approximately halve its burning effect, it must be noted that the pulses were achieved by slowing the venetian-blind mechanism used, i.e. the longer pulses were not designed to simulate the heat flash from large weapons.

The information in Table 1 below, on the thermal doses causing burns to bare skin for various weapon yields, has been obtained from References (1) and (2). Some results with animals are quoted in Reference (3). A graph showing critical radiant exposures for first and second degree burns to bare skin, as a function of weapon yield, has been given in Figure 1 of Section 7.3.1. Attention is also drawn to the Target Damage Charts given in Part I. In using these data for the estimation of burns from high yield weapons the limitations discussed above should be kept in mind.

Table 1

Damage Criteria for Burns to Bare Skin (cals/cm^2)

	Weapon Yield		
	1 KT	100 KT	10 MT
1st degree	2	2.7	3.5
2nd degree	4	5.5	7
3rd degree	6	8	11

References

(1) Staff Officers Field Manual - Atomic Weapons Employment. U.S.Dept. of the Army FM 101-31 (1956) p.71. (Secret Atomic)

(2) Capabilities of Atomic Weapons - U.S. Dept. of the Army, FM 23-200 (1957) p.6-14 (Confidential)

(3) The Thermal Data Handbook. A.F.S.W.P. - 700. Sanitized Edition. 1954. (Confidential).

7.6 Diagnosis and Treatment of Flash Burns

7.6.1 Diagnosis

The recognition of the parchment-like skin, denuded of hairs by singeing, in severe (3rd degree) flash burns, presents no problems once the skin has been cleansed. In more severe burns the skin may be charred. The vivid reddening of slight (1st degree) flash burns is easily recognised. Brief mention must however, be made of the possible errors from hasty diagnosis in blister (2nd degree) flash burns. In the early stages, these injuries show vivid erythema, and if seen less than an hour after infliction no oedema would be discernible. This means that blistering may have to be suspected in all 1st degree burns seen immediately after an attack, with consequent administrative problems. After one hour, or perhaps longer in cold environments where the development of local changes may be delayed by the coolness of the skin, the presence of oedema (swelling) in the burned area must be taken as presumptive evidence that blistering will occur later, so that such cases were better treated to exclude infection.

7.6.2 Treatment

It is now widely recognised by the medical profession that the treatment of flash burns after atomic explosions presents several important features. History has shown that the proper hospital treatment of one hundred or so severely burned casualties presents the medical services, even in peace conditions, with a particularly heavy burden. It has been shown in Section 7.5 that the number of such flash burn casualties after an atomic bomb attack would be very large, especially if the community were not warned, or did not heed warning. It can be calculated from the formula for healing times quoted earlier that the minimum economic burden from 2nd and 3rd degree flash burns after the explosion of the nominal atomic bomb under the circumstances mentioned earlier would be 52,000 man-days per 1,000 persons flash-burned. Simple extensions of this calculation also show that unless such cases were treated, the complications of infection and scarring would result in even heavier long-term burdens on the community as a result of neglect. As a conservative estimate, the previous figure for man-days lost would be raised in the absence of treatment by a factor of 3. Thus treatment under the circumstances considered would save about 100,000 man-days per 1,000 persons flash-burned. The gains from mass treatment are therefore clear. The object of mass treatment would be to provide, as far as possible, the following benefits to each casualty needing one or more of them.

(a) Local treatment - Specific - There is no known specific local treatment for flash burns. Impressed by the possibility that the slow progression of events in shallow blister-burns might be due to noxious substances diffusing downwards from the superficial layers of the skin, Butterfield investigated various measures which might interfere with the process. None of the remedies he tried altered the sequence of events in the burned area.

(b) Local treatment - Early preventative - As a general rule, any flash burn showing blistering or blanching of the skin will require treatment to prevent local infection. The exact methods used to exclude infection from the flash burn will obviously depend upon the resources available, the judgment of the medical attendant, and the man-power available to effect therapy.

(c) General treatment - Early - In those cases where (2nd or 3rd degree) flash-burning is extensive, or where other burning injuries complicate flash-burning so that the total burned area is extensive, means should be found to combat circulation changes by restoring the circulating blood volume. This may be done by oral fluids, e.g. slightly salt water or in larger burns by intravenous therapy. Again, many exigencies will dictate the treatment given.

(d) Local treatment - Late - In the case of extensive 3rd degree flash burns, or 2nd degree flash burns which have deteriorated to a similar depth of injury through infection, plastic surgery will be required to restore adequate function. This may be followed by rehabilitation, exercises etc., later.

(e) General treatment - Late - Those flash burn casualties who require more than a single plastic surgical operation to repair their wounds will almost certainly require extra supportive therapy - special diets and blood transfusions.

7.7 The Prevention of Flash Burns

The methods of reducing flash-burning risks if atomic or thermonuclear warfare seemed imminent may be summarised as follows:-

(a) Dispersion of the population in space and time - Flash-burning is a daytime and especially a "rush-hour" hazard. Any policy designed to reduce the number of persons likely to be outdoors exposed to attack from moment to moment would reduce the risk to the community as a whole.

(b) Warning - Sufficient warning might be given to permit all but essential personnel to seek cover or air raid shelters. This might be difficult for armed forces in the field. With civilian communities, the problem would be that, in the presence of weapons of mass destruction, all warnings would have to be heeded. This would obviously raise serious problems of production and questions of strategy.

(c) Personal protection - For those whose duties placed them out of doors in a position of risk, or for all citizens in the event of a breakdown of warning vigilance, suitable clothing, covering as much of the skin as possible would offer protection. This would be of special importance if it could shield the face, ears and hands, and the legs in women and children. In this connection, it is important to bear in mind that multiple layers of clothing greatly enhance protection, that light colouring enhances protection, but that some fabrics are inflammable and therefore highly unsuitable in such circumstances. A detailed discussion of the protection afforded by clothing is given in Chapter 8.

7.8 The Ocular Hazard from a Nuclear Explosion

Introduction

The maximum dazzle effect produced by a nuclear detonation is sustained when the fireball is seen directly, that is when its image is formed on the retina. In this - the most severe case - the brightness of the source does not vary inversely as the square of the distance when atmospheric attenuation is neglected, for, although at greater distance less light is received by the retina, yet it is concentrated in a smaller retinal image which therefore maintains the same brightness irrespective of distance. The dazzle effect produced by reflected light from cloud or from other highly reflecting surfaces such as snow is affected by distance, since the light reflected by these surfaces is a factor of the light incident on them, and this varies inversely as the square of the distance of these surfaces from the source.

The effects on the retina produced by a nuclear detonation differ from those on the skin surface by virtue of the blink reflex, which acts like a shutter in front of the retina and can therefore prevent it from receiving the high intensity light for the entire duration of the explosion cycle. The exposure received by the eyes thus depends on whether the eyes have blinked and whether, having blinked, they have reopened to look again at the fireball.

The effect produced by the stimulus is therefore caused to vary, but even if the stimulus were constant and known, a number of other variables would have to be taken into account. The most fundamental of these is related to the subject's task. How much dazzle can he tolerate? At night does he require night vision, and if so how much? Has he merely to observe instruments which can be floodlit to a required level if he is dazzled? What part of his visual field is exposed to the dazzle source - his fovea or the peripheral visual field? Were his eyes moving when the flash of light was received? Was the flash received by both eyes in corresponding points of the retinae? What is the nature of his task: is it one of legibility of instrument markings, or is it from perception? What is the probability of being dazzled anyway?

These are some of the variables which have to be considered in assessing the effects upon vision of an unexpected nuclear explosion, and it will be obvious that to provide reasonably accurate quantitative data as to the effects produced in all situations is quite outside the scope of this manual.

The following section however attempts to give the reader the necessary background so that he may be able to form some judgment as to the severity of dazzle likely to be sustained. Towards this end, graphs are provided from which the expected luminance can be assessed and from which one can calculate dazzle recovery times to enable one to see a specified test at a given illumination. The reader should then be able to assess whether in the problem he is considering, the visual effects are likely to be above or below this known value.

The data which will be provided are based partly on theory, and partly on experimental work in which measurements were made of the dazzle produced by looking at a nuclear explosion without any protection other than that given by an exposure which was timed to last 1/10th second from the start of detonation.

Degree of Retinal Damage

As already pointed out, if atmospheric attenuation is neglected then retinal burns and dazzle, which are both dependent upon the optical system of the eye, are affected by distance only in that the area of retina involved becomes smaller as distance from the explosion centre increases. Only when the resolving power of the retinal mosaic is reached does the apparent brightness of the source decrease with increasing distance. It is then physiologically a point source.

There is ample evidence that retinal burns can be produced by nuclear explosions just as similar burns can be produced when the sun is observed for too long as, for example, during a solar eclipse. In the later stages of healing, a severe burn may be associated with such complications as retinal detachment, but its immediate tactical importance is that the subject will have a permanent blind spot equal in size to the burnt area. If the burn is other than in the line of sight, it may, depending upon its size, cause only slight impairment of ability to complete a task. Even in the line of sight however it may still be possible to read instruments if the area involved is less than 2°.

Since there are categories of slight retinal damage which can also be classed as severe dazzle, the operational problems posed by retinal burns and by dazzle must be regarded as one, the problems associated with retinal burns being merely an extreme form of those associated with dazzle.

If a severe retinal stimulus should be received, the chances of successful completion of a mission and of return to base may well depend upon training, for as the stimulus severity increases so the results of that stimulus cause more stress. Consequently a visual task which may be completed satisfactorily in a laboratory, may, in the field, become too difficult as the visual stress summates with the other stresses of the task. Training not to look at the detonation after a blink; shutters to improve upon the blink reaction time should an explosion take place near or in very clear air; if necessary, transparencies to enable the wearer to see instruments by the reflected light from clouds and yet not be dazzled: these are some of the protective measures, but training is by far the most important because under certain conditions protective devices may fail. The dazzle from clouds calls for similar measures, but the effects will be small compared with the effects produced by the image of the fireball on the retina. Whilst this light from clouds in a night explosion constitutes a major problem to the maintenance of near maximal dark adaptation, this is more of a problem for ground troops than for aircrew whose present duties do not require of them such a high degree of dark adaptation. It is to this question of degree of night vision required that one must attribute the main differences in opinions which have been expressed with regard to the severity of this problem.

Luminance

Since the brightness of the fireball varies with the temperature of the two pulses, one refers to integrated luminance, which is usually considered as being from 10^{-4} seconds (when the fireball is still subtending a very small angle at the eye) to 100 milliseconds (which is about the fastest possible blink reaction time). Fig. 1 shows the luminance calculated on the basis of the temperature for a fireball from a 20KT explosion. From this one can calculate and measure the integrated luminance for explosions of different yields by scaling the time axis by $W^{\frac{1}{2}}$ (where W = yield in kilotons). Thus for a 10 KT explosion the time scaling factor which has to be applied to Fig. 1

$$= \frac{10^{\frac{1}{2}}}{20^{\frac{1}{2}}} = 0.707$$

Since the luminance/time curve is on a logarithmic scale, this scaling merely results in displacing the curve to one side or the other. The integrated luminance for different yields is shown in Fig. 2. This was calculated as shown above, and refers to the integrated brightness within the period of 10^{-4} to 10^{-1} seconds.

Blink Reaction Times

The reason for considering integrated luminance up to 100 milliseconds is that this is approximately the duration of the fastest blink reaction time. Studies carried out by Cobb and Sears (Ref. 1) show that about 40 milliseconds after a light has been switched on, there can be detected in the electromyogram, the activity which accompanies the initiation of lid closure. This closure however does not occlude the pupil completely until 100-200 milliseconds after the flash.

Irving (Ref. 4) has found the reaction time to complete occlusion of the pupil by the lid is of the order of 100-150 milliseconds. He has found that the shorter times are associated with stimuli nearer to the fovea as well as with higher intensity stimuli. Thus the reaction time is dependent to some extent on the intensity of the perceived stimulus. As indicated by Cobb and Sears however, the stimulus need not be one of light, for any stimulus can give rise to a blink response. They suggest that the nervous pathway may be cortical and indeed one finds that the blink reflex is amenable to training. Thus a subject can either be trained not to blink when a flash appears or he can be trained to blink and to keep his eyes closed. Training in this connection consisted of verbal instruction and experience. The blink reflex associated with corneal stimulation is however unaffected by training and probably involves lower pathways mediated through the long ciliary nerves from which the cornea receives its nerve supply.

Dazzle

Fig.3, which illustrates the results of experiments, shows the recovery times after flashes by various amounts of light, all of which were delivered to the eye within 2 seconds (Ref. 7). It is possible to verify the shape of this curve by comparing the results obtained by different workers. Although recovery times measured are not necessarily to the same threshold and although different workers employed different criteria such as absolute threshold, form or legibility, these differences introduce a factor which can be considered as constant for each experiment.

The curve marked BHC was obtained by Crawford (Ref. 2), employing flashes of different durations on the fovea, and shows recovery times to 0.14 ft/L. Although his test object was similar to that employed in experiments CS and CI he shows longer recovery times. The data marked U.S. were obtained by Metcalf and Horn (Ref. 5) by looking at the carbons of a searchlight. Their recovery times refer to a threshold of 0.07 ft/L. The curve marked CS was obtained with a tungsten source, whilst point CI was obtained by observing a nuclear explosion (Ref. 9). It can be seen that the curves for each of these reports lie parallel to the curve obtained with the data of the sun experiments (Ref. 7 FPRC.787). It seems reasonable, therefore, to accept the form of this curve as representative of changes in recovery time.

In dealing with the problems of detecting a small square of light of luminance 0.14 ft/L against a black background, it is preferable to use the curve CS-CI for which this task was the specific endpoint. A task involving legibility of lettering will be more difficult and therefore will require slightly longer recovery time, whilst the task involving form perception (if the form subtends a large area) will require a shorter recovery time.

Thus from Figs. 2 and 3 it can be seen that without atmospheric attenuation a 10 KT bomb will in the first 100 milliseconds produce so much dazzle that it will take some 200-300 seconds to see against a black background a source of luminance of 0.14 ft/L, providing the flash has fallen on the fovea. If the explosion is greater than 20 KT, temporary retinal damage will begin to take place.

When considering atmospheric attenuation one would expect less damage in the form of either dazzle or retinal burns to be sustained when witnessing a detonation in the megaton range, for if one were sufficiently far from the detonation not to be seriously endangered by skin burns or by blast, the intervening atmosphere would probably attenuate the luminance to a safe level provided the exposure lasted only 100 milliseconds. To obtain a more accurate assessment of dazzle however, atmospheric attenuation must be taken into account. For this purpose Table 1 below gives the attenuation coefficient of air as a function of horizontal visibility range.

TABLE 1

Visibility (Km)	Attenuation Coefficient (σ)
2	1.2
4	0.98
8	0.5
15	0.268
30	0.132
60	0.066

Consider for example a bomb of 500 KT whose detonation is observed for 100 milliseconds from a distance of 20 Km. when the visibility is 25 Km. (daylight conditions and therefore a pupil diameter of about 4 mm. maximum). What will the luminance be when integrated over the 100 milliseconds period, and how long will it take the observer to recover so that he may see a small square of luminance 0.14 ft/L in darkness and with a natural pupil?

The atmospheric transmission in the visible range = $e^{-\sigma d}$ From Table 1

$\sigma = 0.16$ for 25 Km visibility. d = 20 Km, so the

transmission $\dfrac{1}{e^{.16 \times 20}} = 0.041$

From Fig.2, a 500 KT explosion gives in the first 100 milliseconds, an integrated luminance of 220,000 c/cm^2/sec. With atmospheric attenuation this becomes 220,000 x 0.041 = 9,000 c/cm^2/sec.

From Fig. 3 this amount of light is associated with a recovery time of 100 secs. before a test object of luminance 0.14 ft/L becomes visible through the after image.

Pupil Size

The extent of pupillary dilatation in darkness is often over estimated. There is furthermore, continuous movement of the pupil not only in response to light and shade, but in response to emotional changes, and in general, in response to variations in balance between the ortho and para-sympathetic nervous systems. Variations in accommodation as one looks from near to far also affect pupil size. One can, however, make a reasonable approximation and say that by night conditions the pupil is twice as wide as it is by day conditions (8 mm. and 4 mm. respectively). Thus in Fig. 3, which was for flashes delivered to a daytime pupil, the total stimulating light would have to be multiplied by a factor of 4 if one considers a flash taking place at night, when the subject is also in darkness.

Thus, for example, the 9,000 c/cm^2/sec. calculated above would now be regarded as 36,000 c/cm^2/sec. and the recovery times would therefore according to Fig. 3, become about 300 seconds instead of 100 seconds for the daylight case.

The problem however is not so great, because, if one considers the retinal directional effect of Stiles and Crawford it will be found when the diameter is increased from 4 mm to 8 mm, the effective area of the pupil is not increased from 12 mm^2 to 48 mm^2 but only from 10 mm^2 to 24 mm^2 - an increase of 1.5 times instead of 4.

Probability of Sustaining a Flash on the Fovea

In considering the effect of a very bright extended source whose centre is at various distances from the fovea, it is found that as soon as the edge of the image begins to fall outside the fovea, the recovery times will rapidly decrease to values which are dependent on the amount of intraocular scatter, of atmospheric scatter, or of diffuse reflection from neighbouring reflectors such as clouds.

From one aspect, this is an oversimplification of the problem and recovery times may not in fact decrease as rapidly as the flash goes "off centre" because the scatter and diffuse reflection will be proportional to the luminance of the source. From another aspect however, recovery times may decrease more rapidly than has been suggested, because although foveal vision has here been considered as a point, it is in practice accepted as comprising an area which subtends 3°. Consequently if part of the fovea is left unstimulated, it is still possible to read with little difficulty.

Since there are such differences in the effect on foveal vision produced by a flash taking place directly in the line of sight, compared with one taking place on the periphery, and since the fovea subtends such a small portion of the whole visual field, it is clearly of importance to determine the probability (P) of a flash taking place directly in the line of sight.

Consider a flash occurring in random positions in search fields of different sizes. Different diameters of flash source will be considered, also a fovea in which maximal dazzle takes place only when some part of the image of a circular fireball overlaps on to the central 1°. It is believed that accepting a 1° field instead of an overlap on to the centre of the fovea, as has been found experimentally permissible, will weight the P values so as to compensate for the failure to consider scatter of light.

If the flash source is represented as a point in random positions, the probability of it falling in the 1° foveal field will be in the percentage which the area of the foveal field bears to that of the search field. As the flash is an extended source this fact can be taken into account by increasing the size of the foveal field to $(1 + d)^{\circ}$ where d is the angular diameter of the extended source. When the size of search field is 4π steradians the flash may come from any direction; (the unrestricted binocular field has been estimated to be 1.5π steradians). The results of these calculations are seen in Fig. 4. It is evident, even when considering a small search field subtending a plane angle of 40°, in which the observer knows the explosion will occur, that the likelihood of the flash taking place in direct line of sight is very small, even considering a source which is very large or very near.

This purely mathematical assessment of the risk has been purposely weighted on the side of safety, and in fact the probability of being dazzled by a fireball is less than that which has been suggested, because the maximal effects of dazzle will be sustained if the edge of the fireball comes onto the centre of the fovea and not as has been assumed in this case on the central one degree area.

Eye Movement

In this assessment of the risk no account has yet been taken of eye movements, some of which are so rapid that the image of the distant fireball will be on the retina for only a very short time. According to Westheimer (Ref. 6) some saccadic movements of the eye are as fast as $500\text{-}550^{\circ}$/second. An indication of the effect of such fast movements upon the retinal exposure time to a small source may be obtained by considering a source of 3° angular size and an eye movement of 600°/second. This source will travel its own diameter on the retina in 5 milliseconds and each retinal element in its track would therefore be maximally stimulated for only 5 milliseconds. From experimental work it is known that this exposure would not result in serious dazzle.

In addition to these saccadic movements there are slower movements which are normally present during fixation. When the eye is attempting to fixate in darkness, Ditchburn and Ginsborg (Ref. 3) assess that these involuntary movements are increased by four times in amplitude. This would mean that even during attempted fixation in a dark sky, involuntary eye movements of $\frac{1}{2}^{\circ} - 1^{\circ}$ would be taking place. It is probable that the same amount of involuntary movement would take place when fixation is attempted whilst looking at a bright and empty visual field such as a cloudless sky.

Protective Measures

Training. Two methods of protection are training, and a mechanical shutter. If the mechanical shutter should fail, then recourse will have to be made to training. If a transparent shutter is employed the wearer will again require to be trained. He will have to be instructed not to look at the fireball even through the transparency, because if the fireball lasts for a sufficiently long time he may sustain a burn of the retina just as a retinal burn may be sustained when observing a solar eclipse for too long through a filter which is not sufficiently dense. In this connection the yield of the weapon must be taken into account, since the duration of the explosion depends on the yield. Only with an opaque

shutter will it be possible to eliminate training and then only if the shutter is entirely dependable. It seems unlikely that such a device will be produced because a sensing element operating on flux emitted or on rate of rise of radiation may fail to be triggered by a source which is too far away. That source however may still give rise to a retinal burn if it is looked at.

Training therefore is the first essential in protection from the ocular hazard associated with a nuclear explosion. The training should consist of instruction on the advantage of looking away from a high intensity light source should one appear without warning; on the very low probability of a flash falling directly on the fovea; on the protection afforded by the blink reaction time of between 0.1 and 0.2 seconds, provided the subject does not reopen the eyes and look at the source; it should be pointed out too that the most likely danger is not from a burn of the retina but from dazzle produced by the light scattered by clouds and the atmosphere. This dazzle whilst lasting a long time if one requires to re-adapt to low thresholds need interfere with visibility of instruments only for a few seconds if these have been illuminated by white flood-lighting to a luminance of instrument marking of about 5 foot lamberts or above (Reference 7).

The use of a simulator to give an impression of the angle subtended by a fireball of different yields and at different distances might with advantage be combined with a high intensity light source which could provide a source of calculated dazzle. The effect upon aircrew performance might be demonstrated by giving a flash on the fovea whilst the subject is "flying" an aircraft simulator under simulated night conditions.

Shutter

Whilst more protection may be derived from an opaque shutter, if this device remains over the eyes for the duration of the explosion the pilot who is subject to the effects of a weapon in the megaton range may be blinded for half a minute - not by the dazzle but by the protective shutter over his eyes. It seems therefore that one must have a transparent shutter which at least would enable the wearer to see his instruments should the cabin be illuminated by intense light from the explosion. The transparent shutter would therefore protect principally from dazzle by reflected light, but as already indicated, the subject would still have to be trained not to look directly at the fireball, otherwise his dazzle will be more severe and he may in addition sustain a retinal burn. The filter suggested for such a device is one of neutral density and of 10% -15% transmission which would allow it to be employed also as a sun visor.

Since the eye can look at the fireball directly for as long as 100 milliseconds depending on distance, attenuation, and yield, a shutter need not close in a very short time, and this simplifies the mechanism involved. Thus the difficulties associated with opaque shutters and instrument visibility, could now be solved by a shutter over the canopy. A roller blind type of shutter might be the simplest protective device if it were combined with white flood lighting of instruments.

To the list of protective devices given in Reference 8 should be added the electro-mechanical shutter which has been developed by the United States Air Force. This device consists of two superimposed graticules which when moved by a very small amount render the whole field opaque. The movement is produced by detonation of a small cartridge

which in turn is triggered by a light sensing element. This device has been reported to operate in less than a millisecond. The other device which should be mentioned is a photochromic substance being developed by the National Cash Register Co., in U.S.A. They have produced a substance which, dissolved in various media, changes under the action of light from transparent to dense in a few milliseconds. The process is reversible and when the light is removed the substances becomes transparent again either with equal speed or in several hours depending upon the medium in which it is dissolved. It is claimed that it may be possible to achieve a filter of density 3 by this means, but at present the problems faced are the method of applying this device to goggles in the form of gelatin or to a visor in the form of a fluid sandwich. The sensing element employed with such shutters is usually activated by the intensity of light falling on it. A large distant explosion may therefore fail to a trigger a sensing element which would be triggered by a small explosion at close range or by a large distant explosion in very clear air.

The time in which the shutter has to close must be dictated by such factors as size of the explosion and distance beyond which protection is required, these factors themselves being dictated by the limits beyond which the subject may be expected to survive the effect of blast and thermal radiation.

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PART VI
CHAPTER 7
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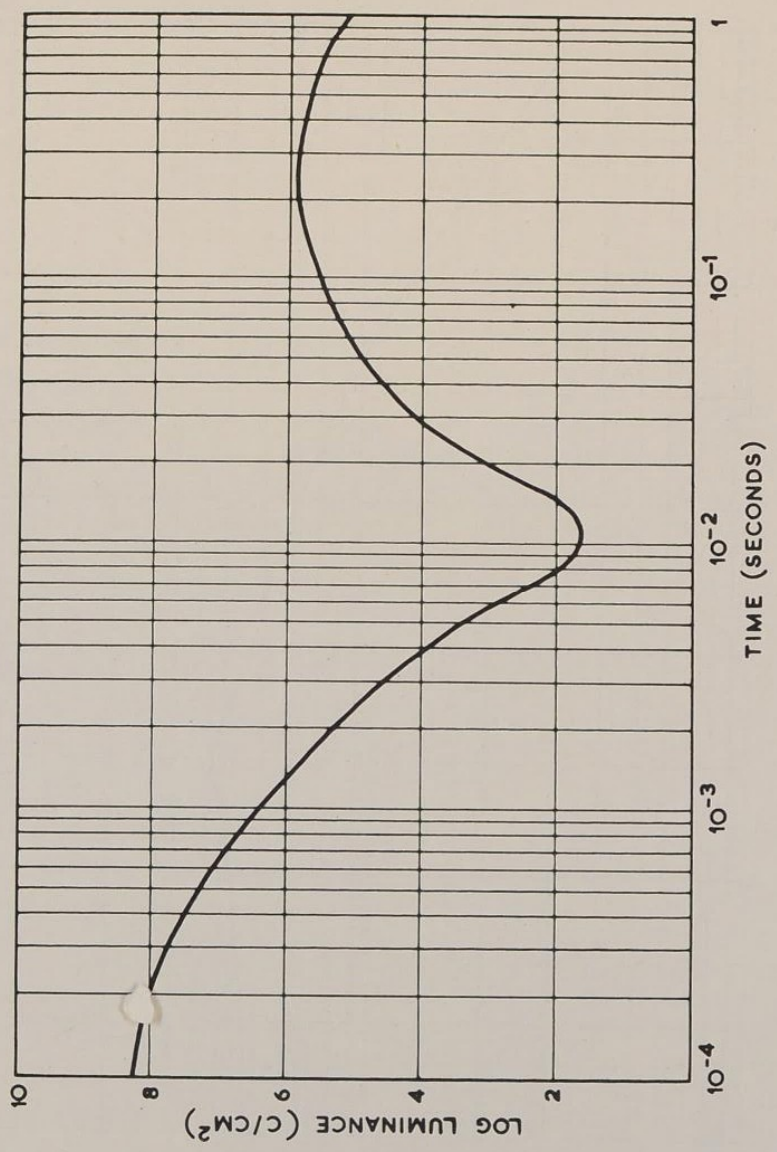
FIGURE 1



LUMINANCE OF FIREBALL
DERIVED FROM TEMPERATURE

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PART VI
CHAPTER 7
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FIGURE 2

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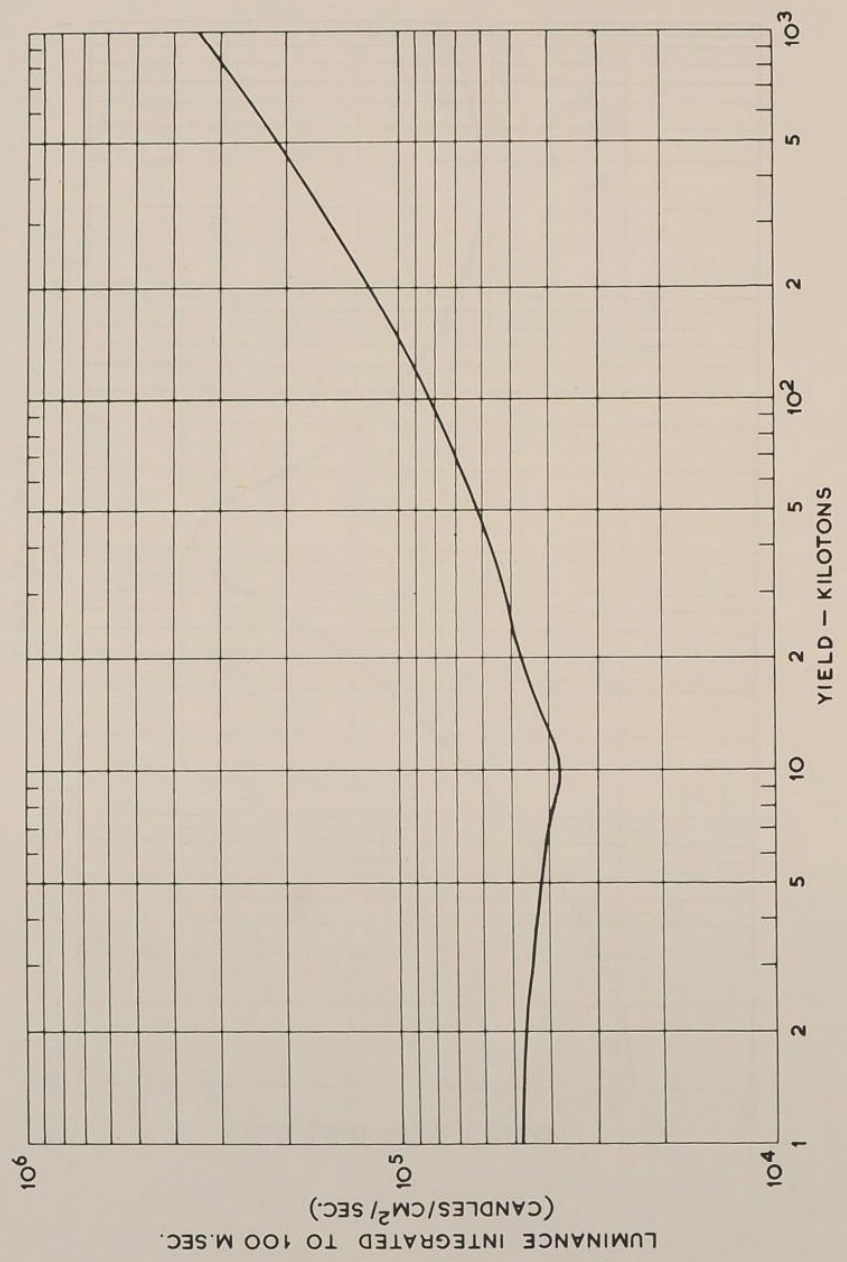
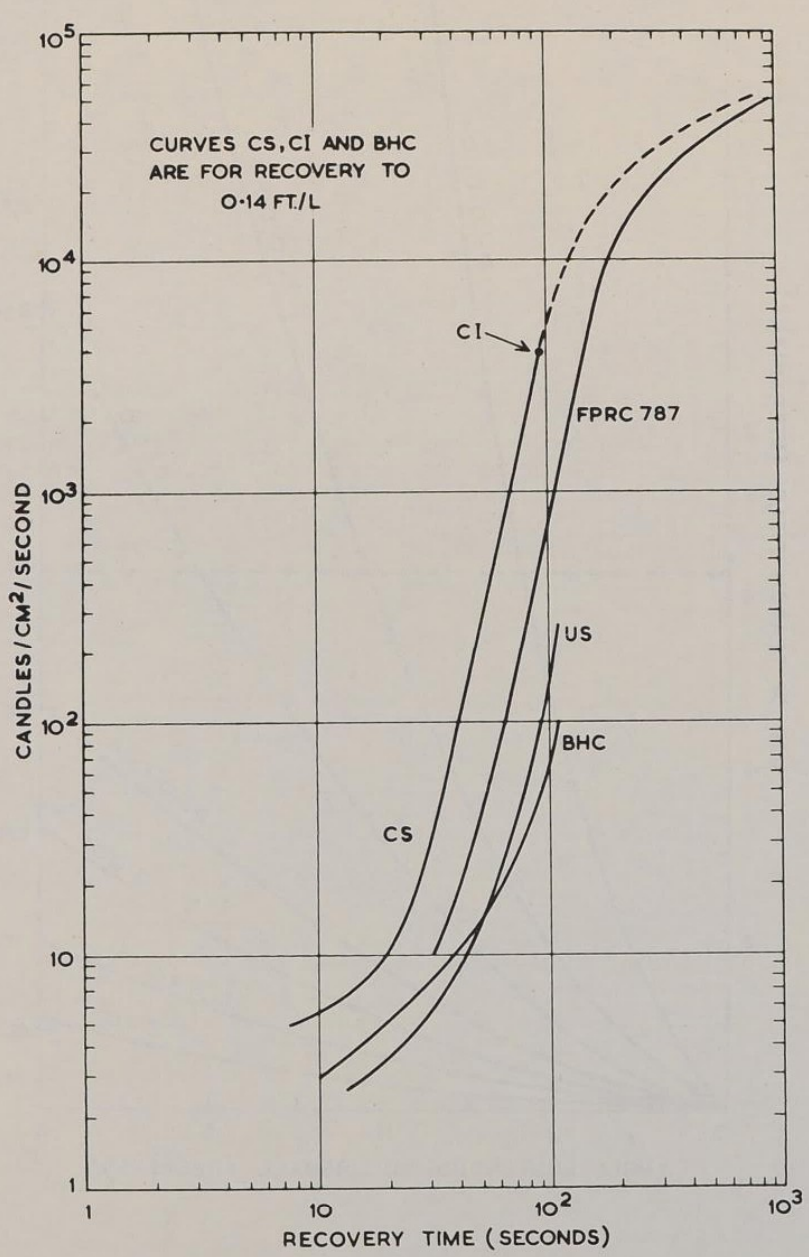
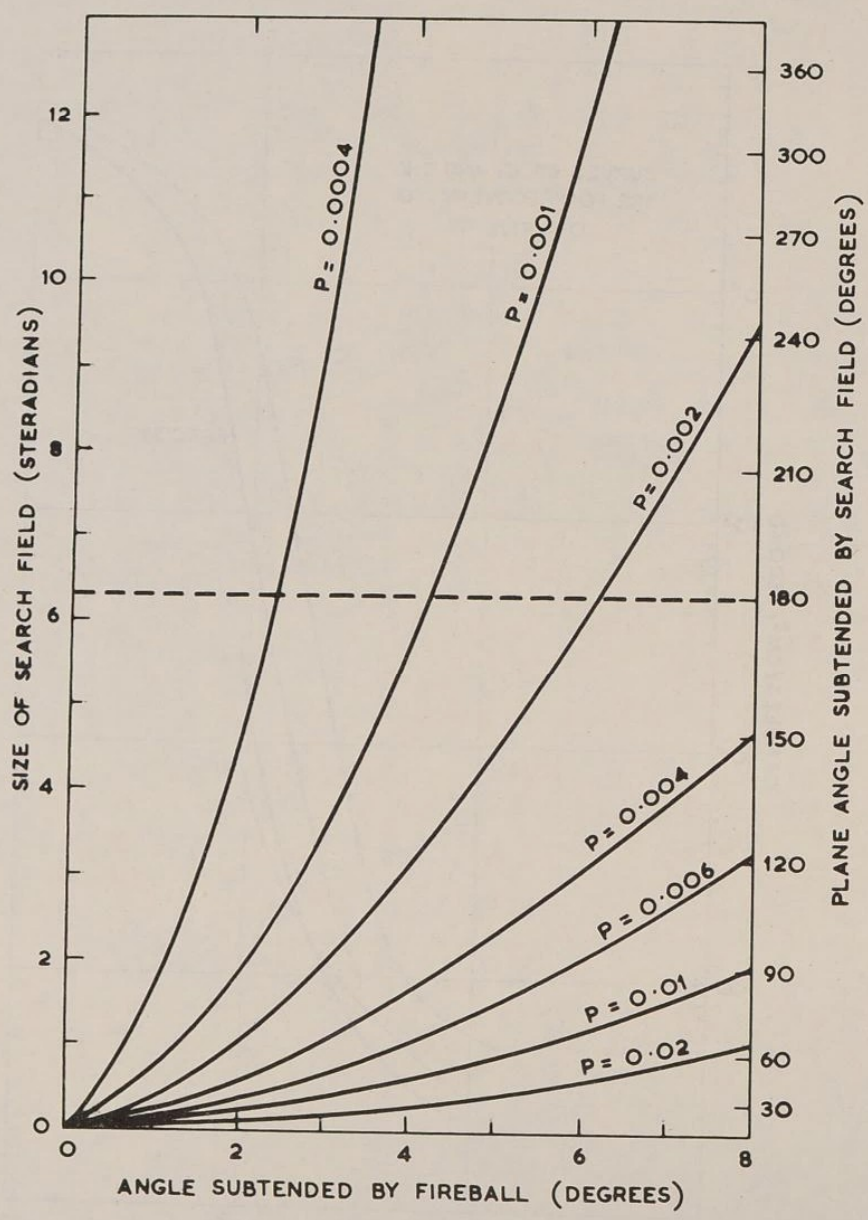


VARIATION OF INTEGRATED LUMINANCE WITH YIELD
(NO ATMOSPHERIC ATTENUATION)



COMPARISON OF RECOVERY TIMES



PROBABILITY OF AN IMAGE OF A FIREBALL FALLING WITHIN THE CENTRAL 1° OF THE FOVEA CENTRALIS

8.3. Full-scale Tests of Thermal Damage to Military Uniforms

The effect of thermal radiation from a weapon of about 15 KT yield, upon full-scale Service clothing assemblies exposed on tailors' dummies, was studied at Operation Buffalo (Reference (1)). The object of the tests was to compare the effects on clothed men with the effects predicted from observations made on small fabric specimens. The results obtained are summarised in Table I.

TABLE I - Effect of Thermal Radiation (Approx. 15 KT Weapon) on Surface Layer of Uniforms and Fabric Sample Assemblies

Thermal Dose Cals/cm^2	Battledress		Combat Suit		Tropical Suit KD/	
	Full Scale	Sample	Full Scale	Sample	Full Scale	Sample
1.3	-	0	-	0	-	0
2.0	-	0	-	0	-	0
2.6	-	0	-	0	-	0
3.8	-	0	-	0	-	0
5.0	-	2	-	0	-	0
7.2	-	3	-	3	-	2
9.0	2	3	2	4	5*	4
12.5	2	3	3	4	5*	-
16.5	2	4	4	5	5*	-
24.5	4	4	5	5	5*	-
33.0	4	-	5	-	5*	-
51.0	5	-	5	-	5*	-
65.0	-	-	-	-	-	5
85.0	-	-	-	-	-	-
115.0	-	-	-	-	-	5

Code:- 0 = no apparent damage

1 = just perceptible scorching

2 = slight scorching

3 = moderate charring

5 = complete destruction

* = complete destruction of whole assembly and dummy

/ = the tropical suit KD consisted of drill trouser and cellular jacket, whereas the only fabric sample used for comparison was drill.

Conclusions

The following conclusions are made in Reference (1).

(i) The current serge battledress and sateen combat suit, give excellent protection against thermal radiation, except that both types naturally fail to cover all bare skin.

(ii) The R.A.F. Service dress also gives excellent protection, but it is considered that the dark blue colour may slightly reduce its protection compared with khaki battledress.

(iii) The tropical uniform offers very little protection and may in fact increase the effect of thermal radiation by ignition.

(iv) The R.A.A.F. flying suit is similar to tropical uniform in that it easily ignites and is therefore unsatisfactory with respect to thermal protection.

(v) The oversuit tank crew is unsatisfactory because of the low melting point of the plastic outer layer.

(vi) It is considered that the use of small fabric samples to test the effects of thermal radiation on uniforms is reasonably satisfactory.

Reference should also be made to Section 4.2.1 of Chapter 4, which gives an account of thermal effects on textiles, including Service uniform fabrics.

References

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Chapter 8
Section 8.4

D1/57
November, 1958

8.4. Critical Radiant Exposures for Burns under Clothing

The complexity of the interrelations among the factors which control the protective value of clothing assemblies (see Section 8.1) makes an accurate prediction extremely difficult. Table 1 lists estimates of radiant exposures required to effect burns under clothing and is based on information obtained from References (1) and (2). These values are considered representative of average field conditions, but it should be remembered that they are dependent upon many variables which are not easily defined, and are probably correct within a factor of 2. Additionally, in extremely cold or wet weather, the thermal intensities required for burns are considerably increased.

Table 1

Critical Radiant Exposures for Burns under Clothing
(expressed in cal/cm^2 on outer surface of cloth).

Clothing	Burn	1 KT	100 KT	10 MT
Summer Uniform (2 layers)	1^o	8	11	14
	2^o	20	25	35
	3^o	25	33	44
Winter Uniform (4 layers)	1^o	60	80	100
	2^o	70	90	120

References

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PART VII - DAMAGE BY NUCLEAR RADIATION

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CHAPTER 2 - BIOLOGICAL EFFECTS OF NUCLEAR RADIATION

2.1. The Nature of Biological Effects on Man

As explained in the introduction to Part VII, the nuclear radiation effects of an atomic explosion may be divided into two categories, namely, the initial radiation (gamma rays and neutrons) and the residual radiations (gamma rays, alpha and beta particles). Although different radiations may cause ionisation by different mechanisms and to varying degrees, the ultimate biological response of cells composing living tissue exposed to these radiations is to suffer cellular damage or destruction.

The effects of nuclear radiations on man depend however, not only on the total radiation absorbed, but on the rate of absorption. The generally accepted explanation for this is that if the dose-rate is small the damaged tissues have a chance to recover, at least partially, but where intensive radiations are received the recovery cannot keep pace with the damage. This fact makes it necessary to distinguish between acute exposure (a single short dose of radiation) and chronic exposure (a prolonged dose). Exposure to the initial radiations from an atomic bomb, which are taken as being of one minute's duration, may therefore be regarded as acute.

The gamma (or X-) radiation dose received by an individual is described in terms of the roentgen unit (r) (see Glossary for definition). It is a measure of the strength of the radiation field at a given location, and the radiation dose in roentgens is therefore referred to as an "exposure dose". Neutron radiation dose may be estimated by the rem (roentgen-equivalent-man) unit, which is the amount of energy absorbed per gram of mammalian tissue to give the same biological effect as one roentgen of gamma or X- radiation.

Table 1, taken from Reference (1), gives an approximate indication of the early effects on human being of various acute doses of radiation, assuming exposure of the whole body. Individuals may, however, vary considerably in their reactions to nuclear radiations.

TABLE 1

Acute Effects of Whole Body Penetrating Ionizing Radiation on Human Beings

Dose in 1 week	Effect
0-150 r	No acute effects - serious long term hazard.
150-250 r	Nausea and vomiting within 24 hours, minimal incapacitation after 2 days.
250-350 r	Nausea and vomiting in under 4 hours. Some mortality will occur in 2-4 weeks. Sympton free period 48 hours-2 weeks.
350-600 r	Nausea and vomiting under 2 hours. Mortality in 2-4 weeks, or prolonged incapacitation.
600 r	Nausea and vomiting almost immediately. Mortality in 1 week.

1 rad is the unit of absorbed dose, equal to 100 ergs per gram of tissue. The relative contribution of neutron and gamma radiation to total biological dose is shown in Figure 3, taken from Reference (2).

Neutrons transfer energy to the tissue by a different mechanism from that of gamma rays, and produce greater biological damage. The relative biological effectiveness (RBE) is the ratio between the quantity of energy delivered to the tissue by gamma rays compared with neutrons to produce the same biological effect. For many observed biological effects neutrons appear to have an RBE 1-4 times that of gamma rays, but in some instances values as high as 15-30 have been found (Reference(1), page 184). The production of cataracts (lens damage) appears to have an RBE of 4-8, and this may be a limiting factor in determining permissible exposure to neutrons. In Reference (2), page 468, it is recommended that a value of 1.7 be taken for the RBE for casualties from bomb neutrons. This figure has been obtained from observations on mice, but some confirmation is given by analysis of data on radiation injury and death after the nuclear explosions in Japan.

Further more detailed accounts of the biological effects of initial radiations may be obtained from Reference (2), page 466, and References (3), (4), and (5).

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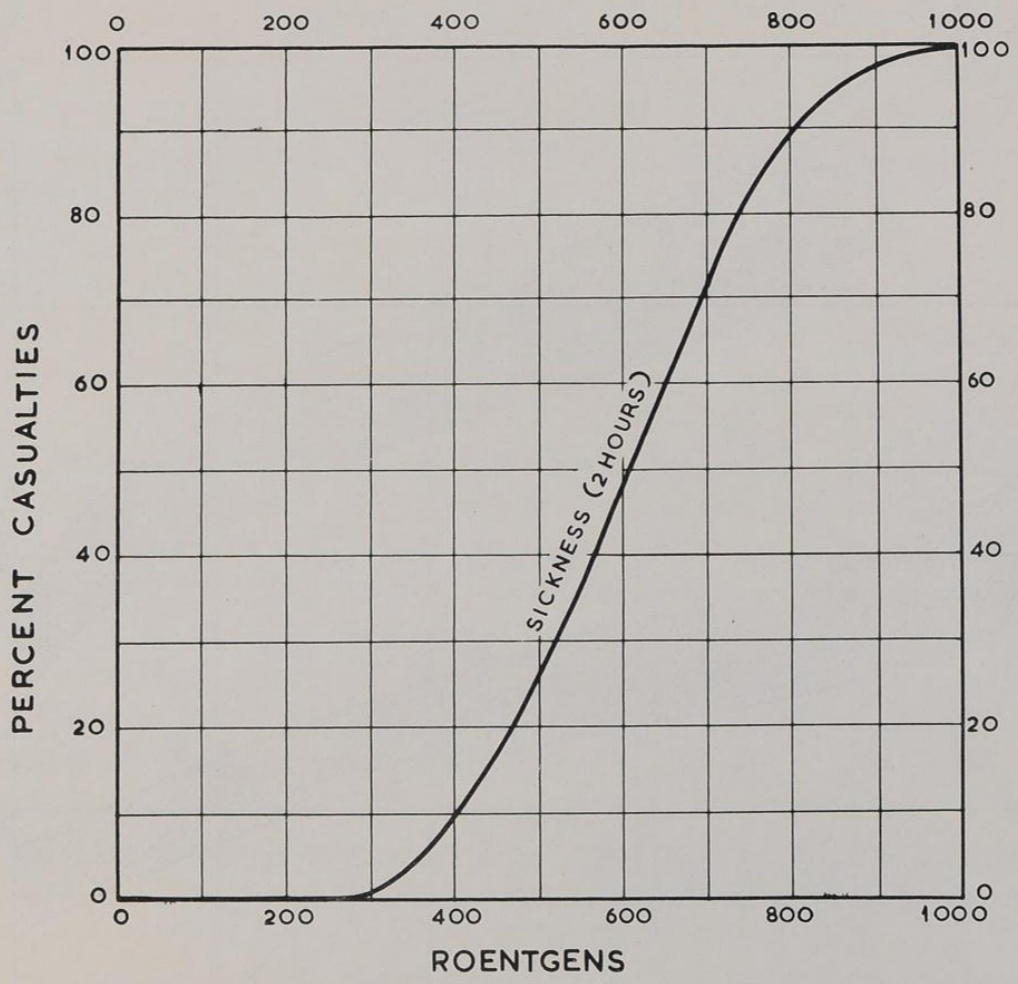
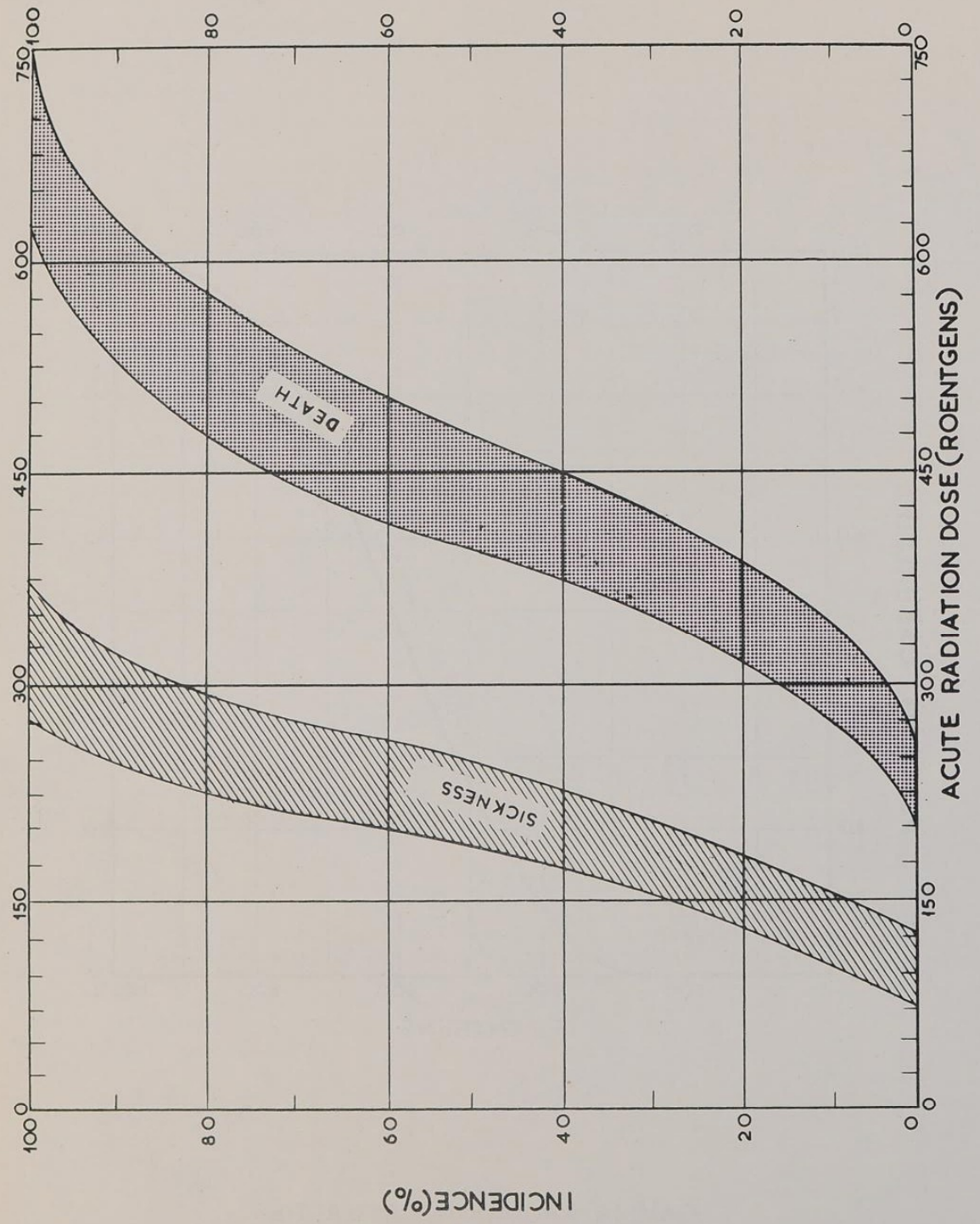


GAMMA RADIATION CASUALTIES
WITHIN 2 HOURS

D.N.W.
JAN.1958.



INCIDENCE OF SICKNESS & DEATH DUE TO ACUTE EXPOSURE TO VARIOUS DOSES OF NUCLEAR RADIATION

2.3. Effects on Man of External Residual Radiations

If radiation from surface contamination and fallout is to have any biological effect it must pass through the horny layers of the skin. Because of their very short range in air, and even shorter range (about 0.05 mm) in tissue, alpha particles are of no importance as an external radiation hazard.

Beta particles: These may penetrate a few millimetres in tissue, but do not reach the bone marrow or other inner parts of the body. Skin injuries ranging from reddening to blisters and sores may result from exposure to beta emitters, and these injuries can cause incapacity similar to that resulting from thermal burns. Depending on the dose received, the incapacity can begin as early as 4-6 hours, or as late as ten days, and the resulting injury may last for several months. The probability of exposed persons obtaining beta burns from fallout may be considerably reduced by immediate action such as bathing and change of clothing. The longer fallout remains in contact with the skin the more severe and extensive the beta burn is likely to be. Radiation sickness is not expected to accompany the skin injuries caused by beta particles. The acute effects of ionising radiation on the skin are given in Table 1, taken from Reference (1). The doses in this Table are expressed in 'rads', where 1 rad is by definition the unit of absorbed dose, and equals 100 ergs per gram of tissue.

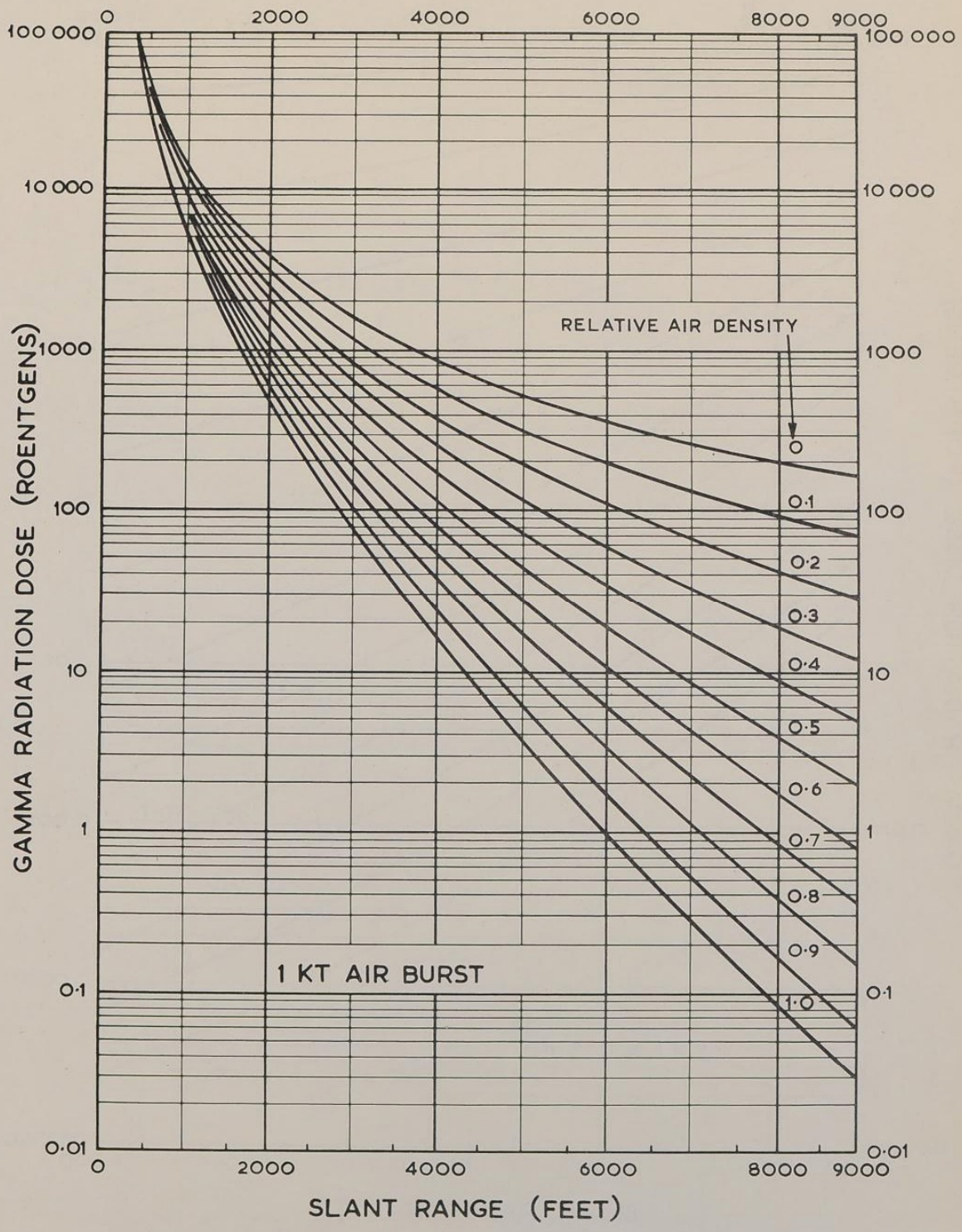
TABLE 1

Acute Effects of Ionising Radiation on Skin

Estimated dose required in 1 week (rad)	Effect
0-600	No accute effects
600-2,000	Moderate early erythema
2,000-4,000	Early erythema under 24 hours. Skin breakdown in 2 weeks.
4,000-10,000	Severe erythema in 24 hours. Severe skin breakdown in 1-2 weeks.
10,000-30,000	Severe erythema in 4 hours. Severe skin breakdown in 1-2 weeks.
30,000-100,000	Immediate skin blistering (less than 1 day).

Gamma rays, being much more penetrating than alpha or beta particles, are the most hazardous type of external residual radiation. The mean energy of the gamma ray photons from residual radiations is about 0.7 Mev compared with about 3 Mev for initial gamma radiations. Residual gamma radiation is therefore less penetrating than initial radiation.

Little evidence is available of the ultimate effects of prolonged human exposure to moderate gamma radiation, such as might be experienced in a contaminated area, but the effects of tissue recovery may influence the degree of injury sustained. The total dose received is the basic criterion for injury to personnel; but if the time of exposure increases, then the total dose required to produce incapacity increases also. For example, on the average, 50 percent deaths would occur in persons exposed to an acute dose of 450r. On the other hand, exposure to 15r per day for 30 days would produce limited casualties and probably no deaths, (see Table 2, Chapter 2, Section 2.1). On a lesser scale of exposure it is expected that persons who received 0.1r daily for years would show no ill effects. In general, the clinical symptoms and biological effects of chronic doses of gamma radiation over the whole body are expected to be similar to those for acute doses, the severity of the effects increasing with dose rate and cumulative dose.



INITIAL GAMMA RADIATION DOSE AS A FUNCTION OF SLANT RANGE FOR VARIOUS RELATIVE AIR DENSITIES

PART VII
CHAPTER 3
SECTION 3.1
FIGURE 1 B

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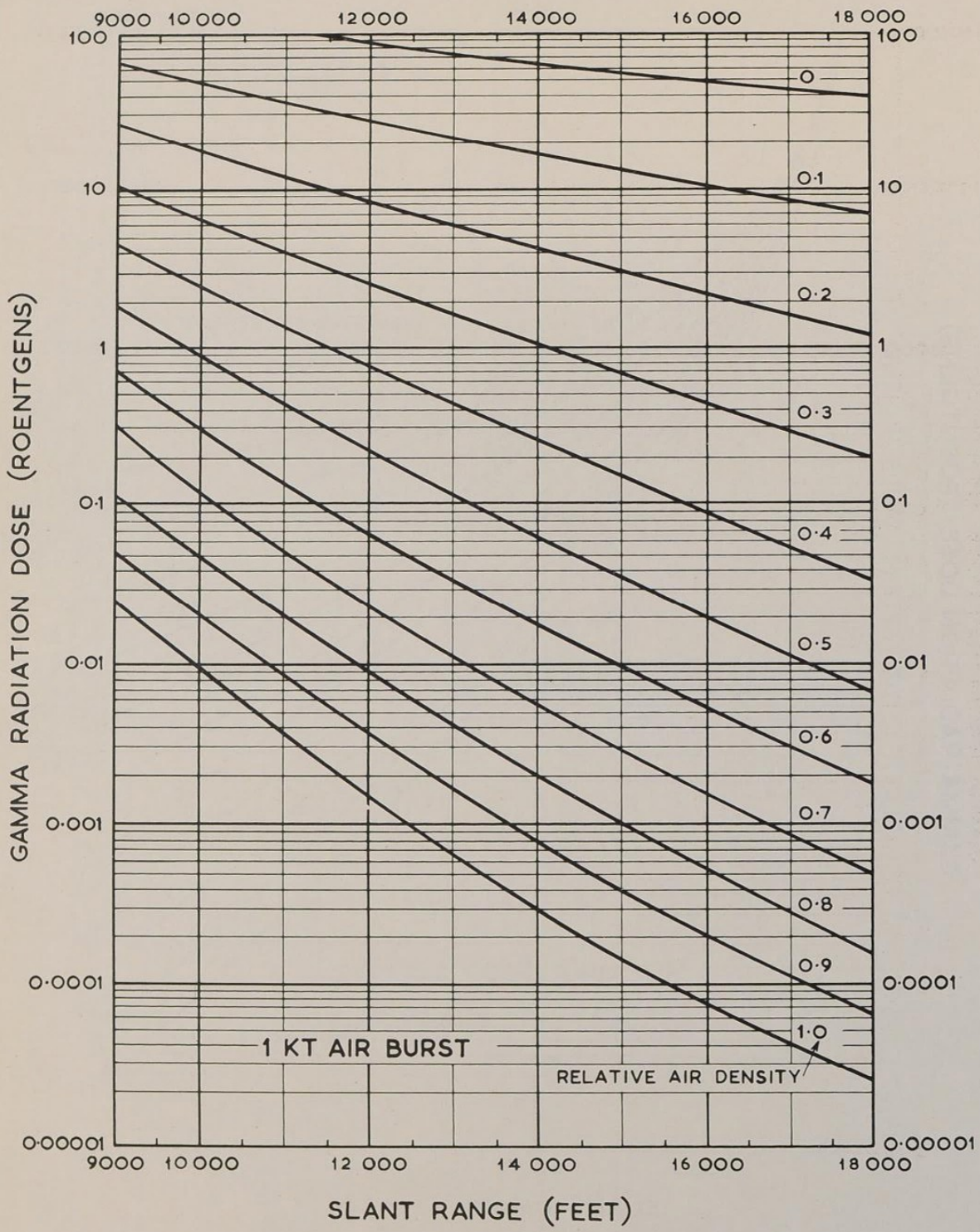
ATOMIC



INITIAL GAMMA RADIATION DOSE AS A FUNCTION OF SLANT RANGE FOR VARIOUS RELATIVE AIR DENSITIES

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ATOMIC

PART VII
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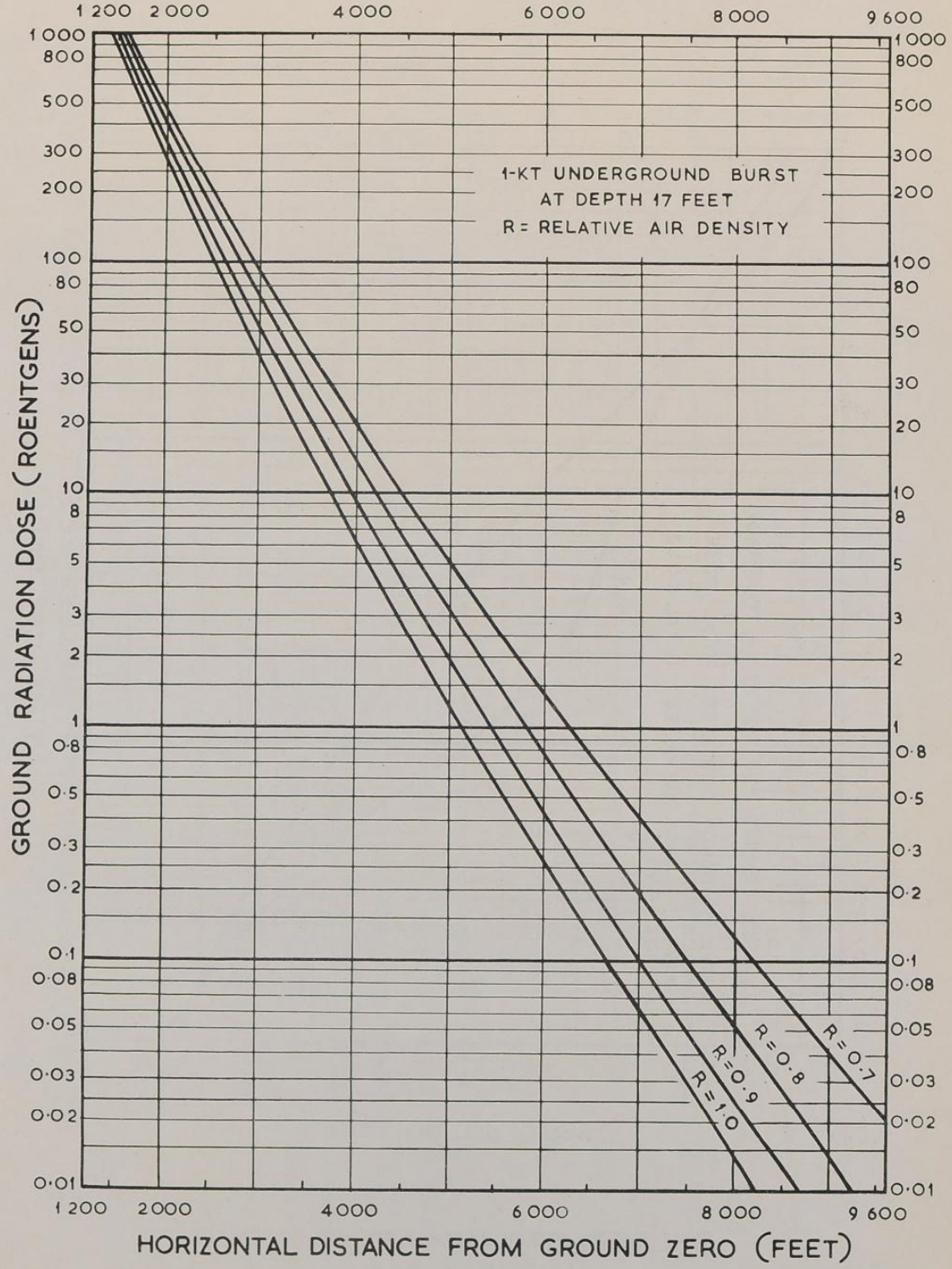
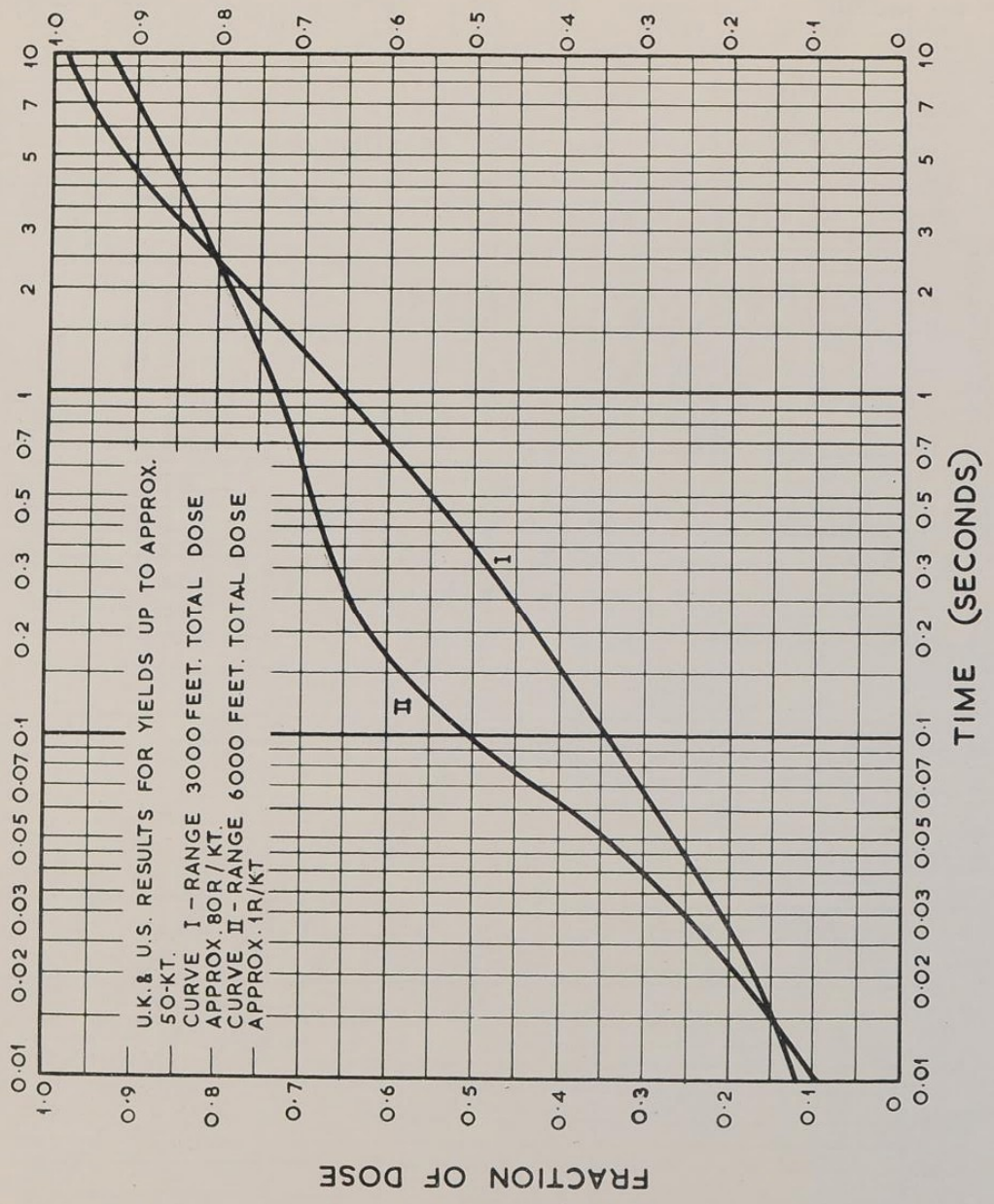
SECTION 3.1
FIGURE 3

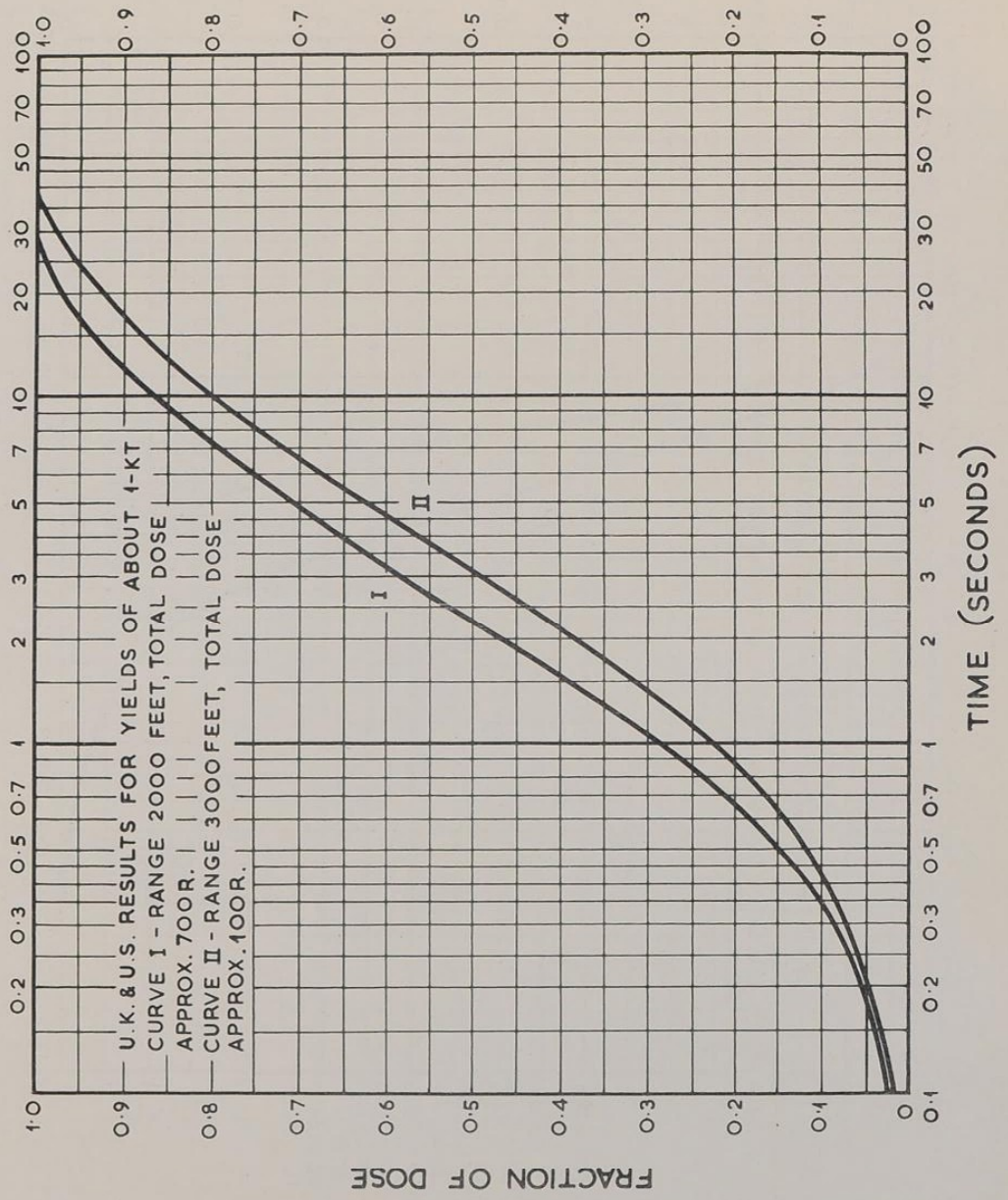


INITIAL GAMMA DOSE/DISTANCE CURVES FOR
1-KT UNDERGROUND BURST

D.N.W.
FEB. 1958



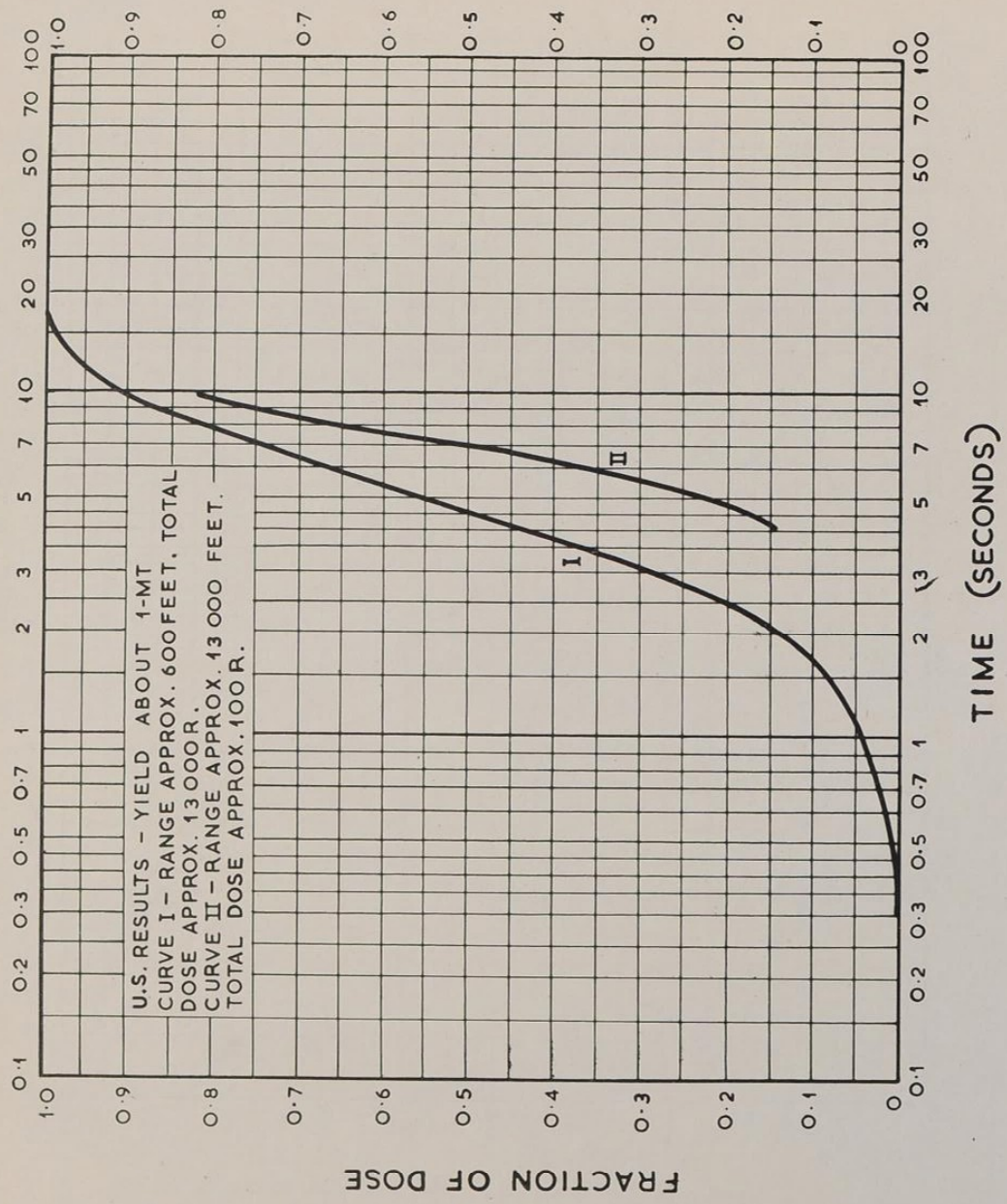
DELIVERY OF GAMMA DOSE IN TIME
AIR BURST



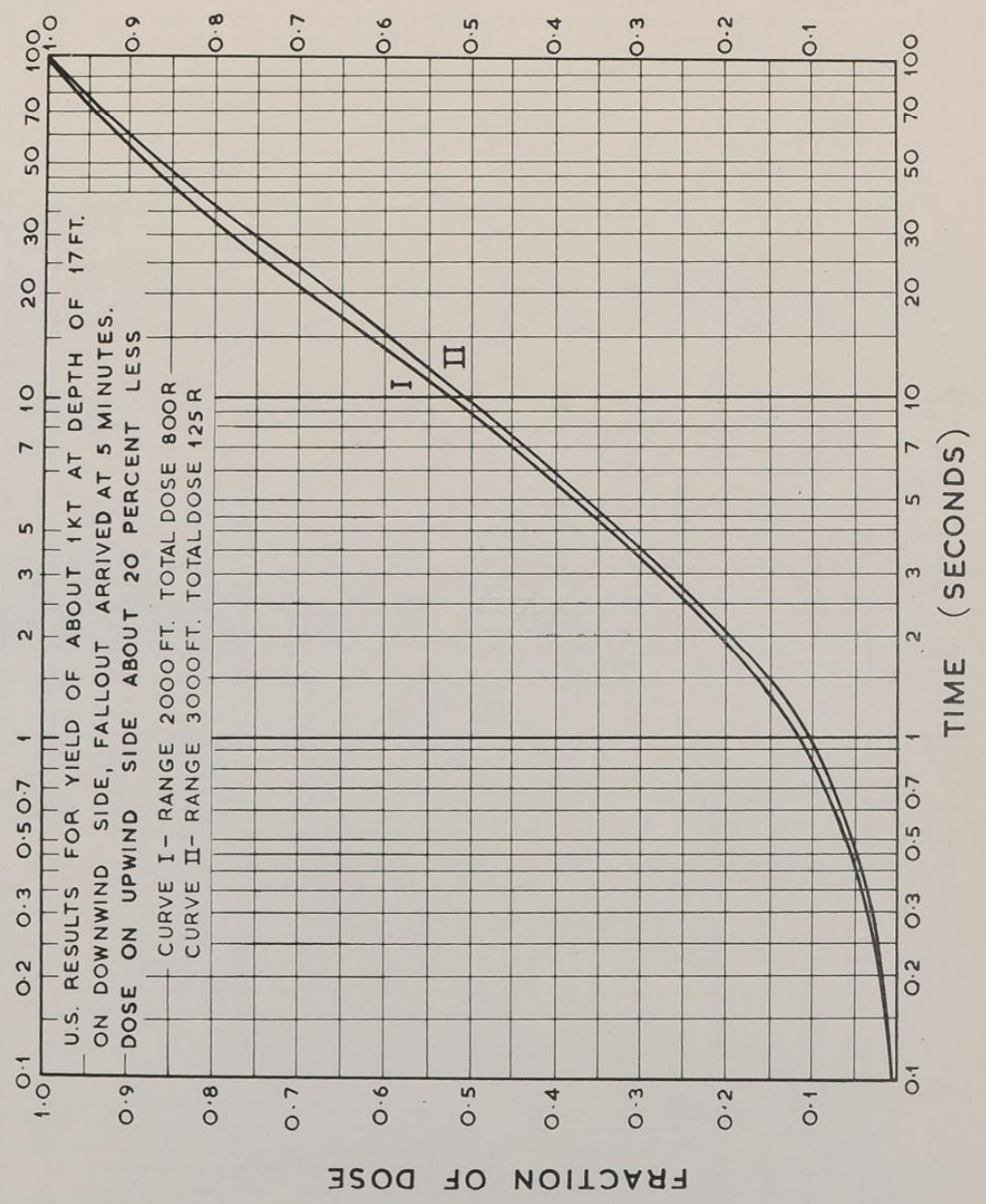
DELIVERY OF GAMMA DOSE IN TIME
SURFACE BURST

PART VII
CHAPTER 3
SECTION 3.1
FIGURE 6

SECRET / ATOMIC
U.K. EYES ONLY



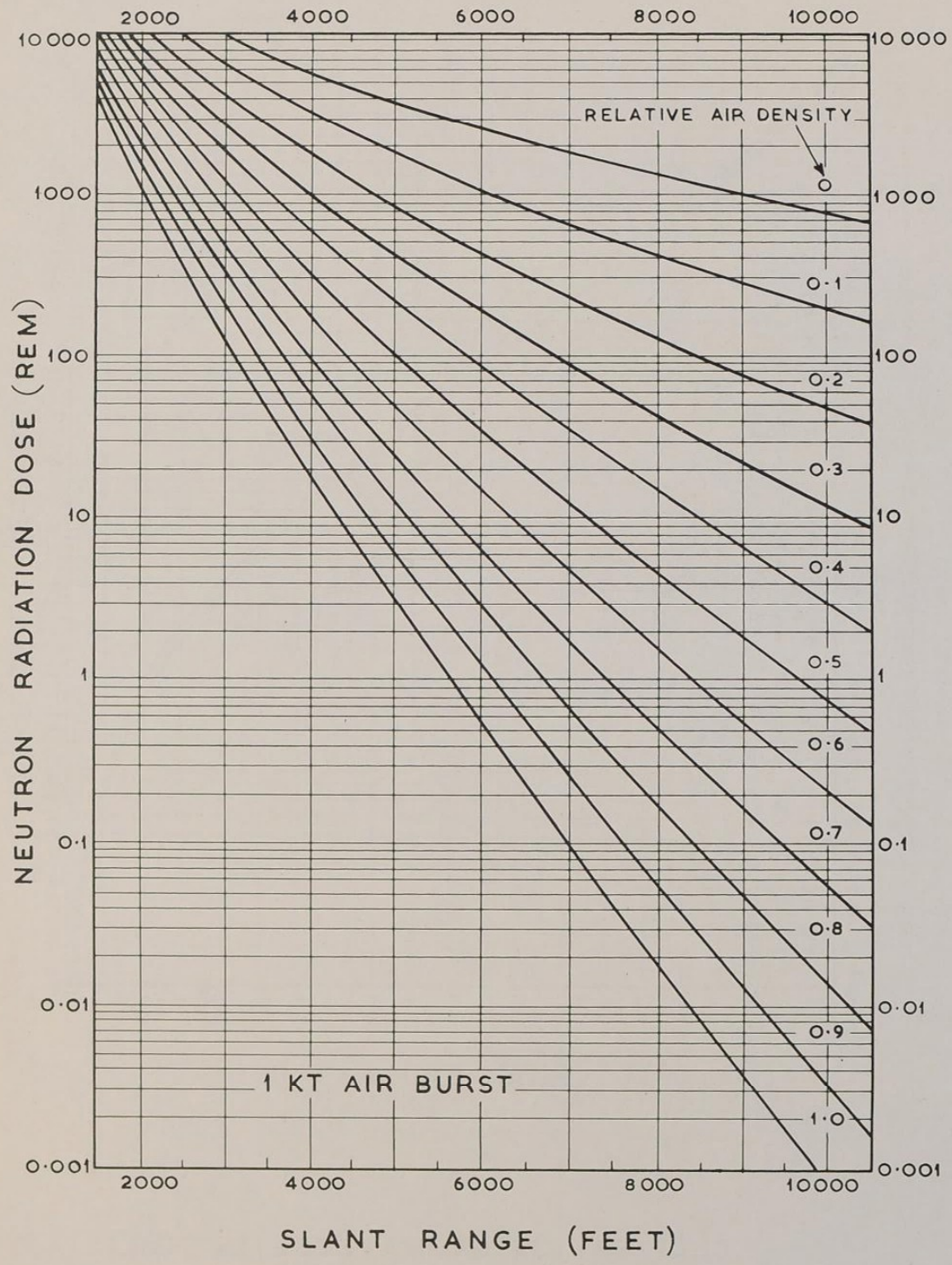
DELIVERY OF GAMMA DOSE IN TIME
HIGH YIELD SURFACE BURST



DELIVERY OF GAMMA DOSE IN TIME
SUB - SURFACE BURST

CONFIDENTIAL
ATOMIC

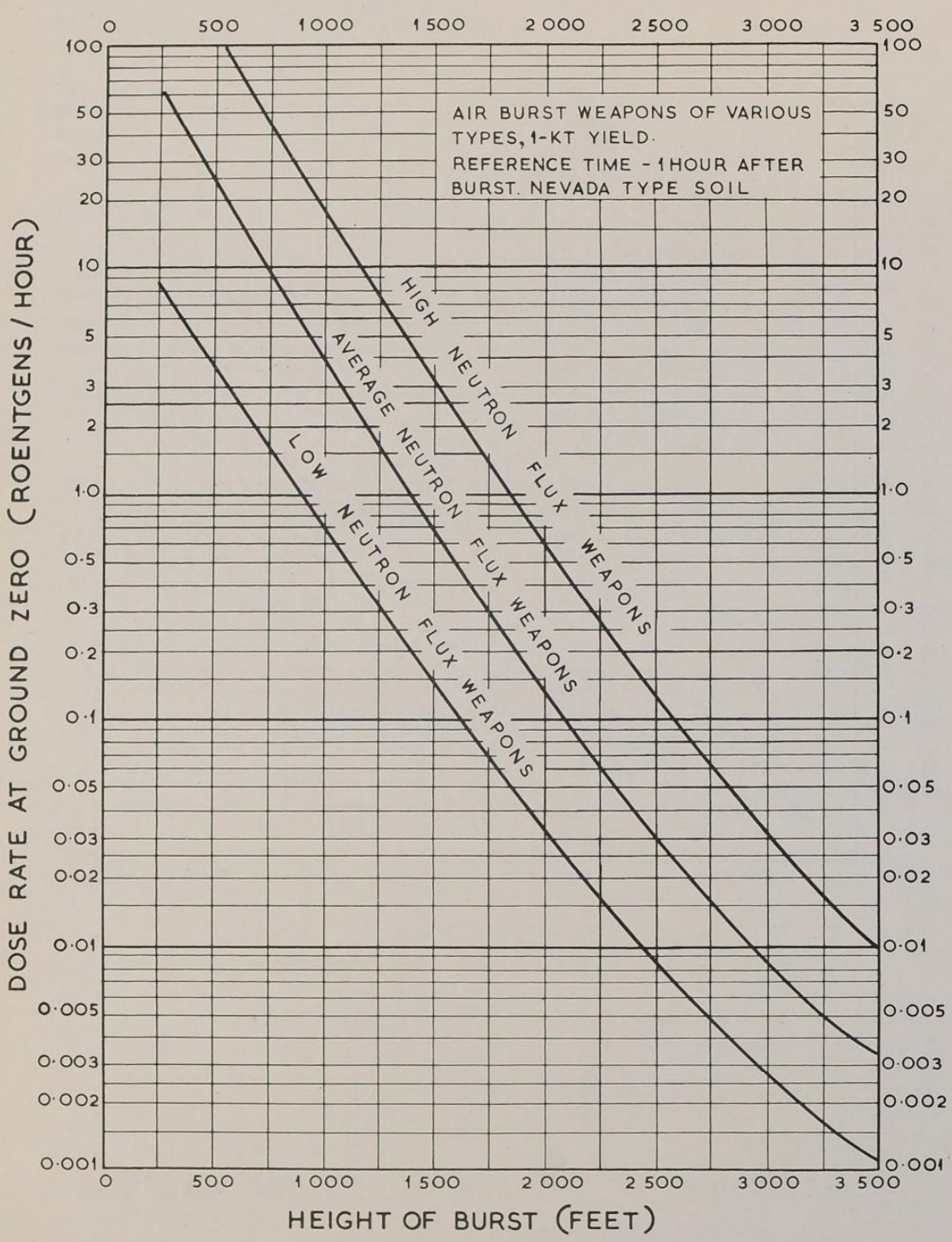
D.N.W.
FEB. 1958



NEUTRON RADIATION DOSE AS A FUNCTION OF SLANT RANGE (HIGH NEUTRON FLUX WEAPONS)

PART VII
CHAPTER 3
SECTION 3.2
FIGURE 4

CONFIDENTIAL
ATOMIC



NEUTRON-INDUCED GAMMA ACTIVITY AT GROUND ZERO

Acceptable emergency beta (or gamma) activities in drinking water, for limited periods of consumption, are given in Table 2, taken from Reference (5), page 535.

TABLE 2

Acceptable Emergency Beta (or Gamma) Activities in Drinking Water

Consumption Period (days)	Activity	
	Microcuries per cc	Disintegrations per second per cc
10	9×10^{-2}	3×10^{3}
30	3×10^{-2}	1×10^{3}

The emergency limits for alpha particle emitters, such as uranium and plutonium, in water are appreciably less than those given in Table 2. However, it is expected that only in rare circumstances would these elements represent a contamination hazard in drinking water.

An assessment of the hazards from the inhalation of radioactive dust from a nuclear explosion is given in Reference (6). Numerous pertinent physical and physiological factors are considered, and field and laboratory investigations analysed. It is concluded that there is no conceivable situation in nuclear warfare where, during the first few days after a detonation, one could inhale sufficient radioactive material to induce a serious radiation injury to lungs or intestines without simultaneously being subjected to supralethal doses of external beta and gamma radiations.

References

(1) Recommendations of the International Commission on Radiological Protection. British Journal of Radiology, Supplement No. 6, 1955.

(2) U.S. Code of Federal Regulations No. 10 (10 CFR), Part 20. "Standards for Protection against Radiation".

(3) A.W.R.E. Report No. O-34/56 - "Ingestion of Food Contaminated by Atomic Explosions". (Official Use Only)

(4) A.W.R.E. Report No. T65/57, Operation Buffalo, Biology Group, Part 4B: "The Effects of Neutron and Gamma Irradiation upon Foodstuffs". (Confidential)

(5) Effects of Nuclear Weapons, U.S.A.E.C., 1957.

(6) Operation Teapot, Project 37.3, Civil Effects Test Group, U.S.A.E.C. (Official Use Only)

5.1.4. Attenuation data for light elements

"Light elements" in this connection are elements with an atomic number less than about 30, that is, corresponding to atomic weights up to about 65 (Zinc). For such elements the preponderant mechanism of attenuation is the Compton effect.

The protective qualities of a shield can be defined by the "attenuation factor", which is the ratio of the dose immediately behind the shield to the dose which would be at that point in the absence of the shield. Methods of computing attenuation factors for simplified conditions have been described in References (1) and (2). Figure 1 is based on those methods applied to radiation beams perpendicular to a concrete shield of density 144 lb./cu.ft. (2.3 gm/cc). Equivalent thicknesses of other light element materials are inversely proportional to the density of the material. A list of densities of a number of common materials is given in Table 1.

Measurements of dose reduction by concrete shields were made at British trials of weapons in the kiloton range (Operation Totem), References (3) and (4). The results indicated a photon energy of 1 Mev used in the "modified upper limit" method of calculation (Reference (2)) to be satisfactory. For thin shields (less than about six inches of concrete) close enough to the weapon for the free air dose to be greater than 200 r, an energy of about 0.5 Mev is more realistic. Figure 1 is calculated on the "modified upper limit" formulae and therefore may be used without further calculation. More recent results from Operation Buffalo (Reference (5)) differ from those obtained at Totem, and show that the design of the weapon is the dominant factor. The penetration of gamma-rays through concrete slabs at Buffalo appeared to be consistent with exponential attenuation with a half-thickness of concrete corresponding to 51 lb./ft.^{2}. Thus the radiation appeared to be considerably harder than at Totem where the half-thickness correspond to 20-29 lb./ft.^{2}.

Figure 2, taken from Reference (6), gives attentuation factors for various materials as a function of shield thickness.

No experimental results are available for megaton weapons, but because of the probable increase in the amount of $(n.\gamma)$ radiation from nitrogen in the air it is expected that a higher energy would have to be used. Approximate calculations based on U.S. data for "free air" doses suggest about 5 Mev.

It should be noted that the absorption of neutrons in light elements is accompanied by the production of gamma radiation, of which account must be taken. References (7) and (8) give details of this.

References

(1) Cave, Corner & Liston, Proc.Roy.Soc. Vol. A.204, p.223, 1950 "Perpendicular Incidence on a Plane Slab".

(2) Ministry of Supply, H.E.R. Report No. H13/51 (Restricted) "Tables for the Solution of Gamma Ray Shielding Problems".

(3) A.W.R.E. Report No. T53/54 (Secret) - "Penetration of Concrete Slabs by Gamma Radiation".

(4) A.W.R.E. Report No. T20/54 (Secret) - "The Penetration of the Gamma Flash into Anderson Shelters and Concrete Cubicles".

(5) A.W.R.E. Report No. T42/57, Operation Buffalo. "Attenuation and Scattering of Initial Nuclear Radiations". (Secret/Atomic/U.K. Eyes Only)

(6) Effects of Nuclear Weapons, U.S.A.E.C, 1957, p.357.

(7) Nucleonics, Vol. 13 (No.5) pp.50-51. Shielding Constants. Gamma Rays from Thermal Neutron Capture.

(8) Nucleonics, Vol. 15 (No.4) pp.84-85. Induced Radiation. Radiation from Neutron Activated Slabs and Cylinders.

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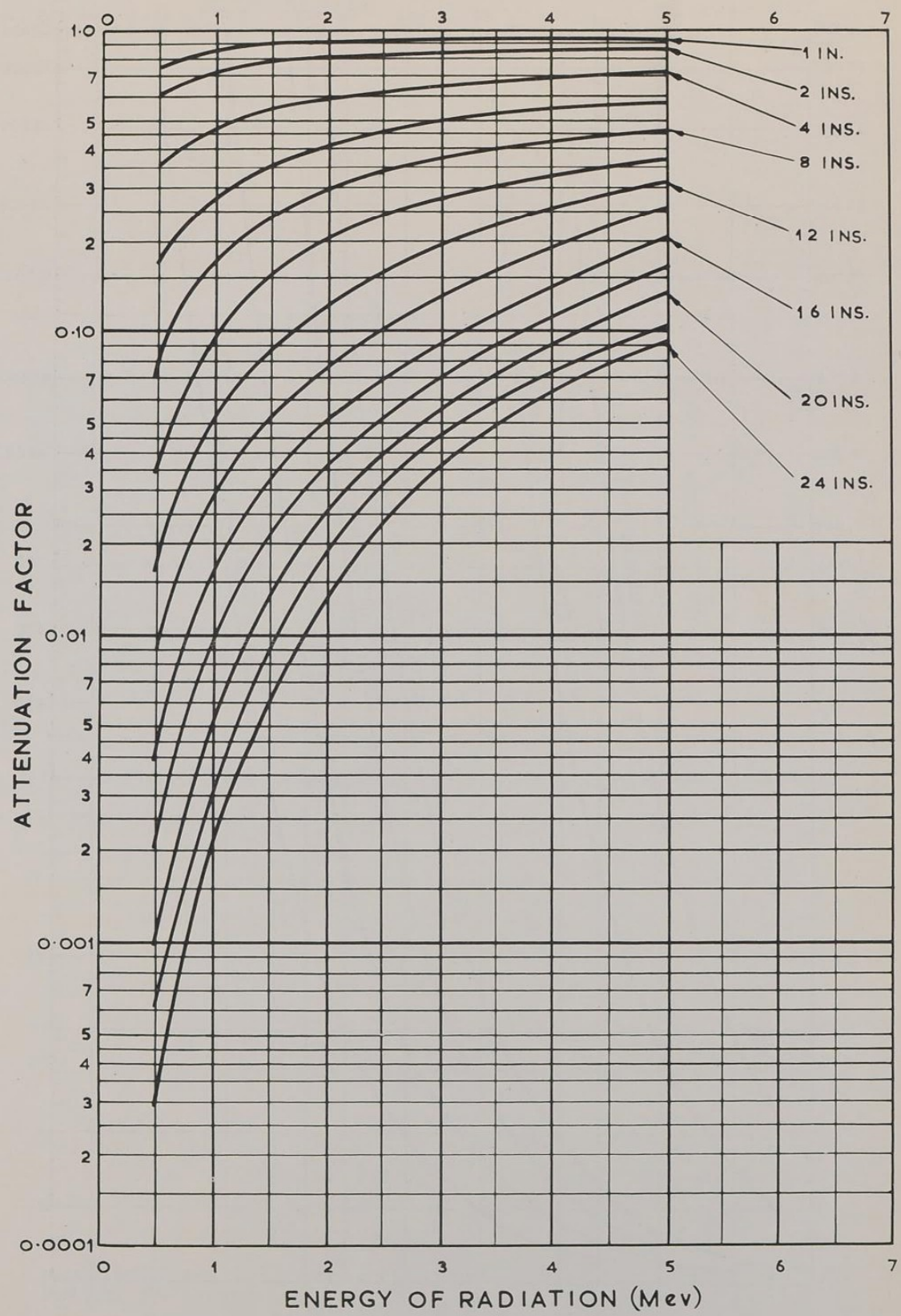
CHAPTER 5
SECTION 5.1.4
FIGURE 1



ATTENUATION FACTORS FOR GAMMA RADIATION FOR LIGHT ELEMENT SHIELDS (DENSITY 144 LB. PER. CU. FT.)

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FIGURE 2

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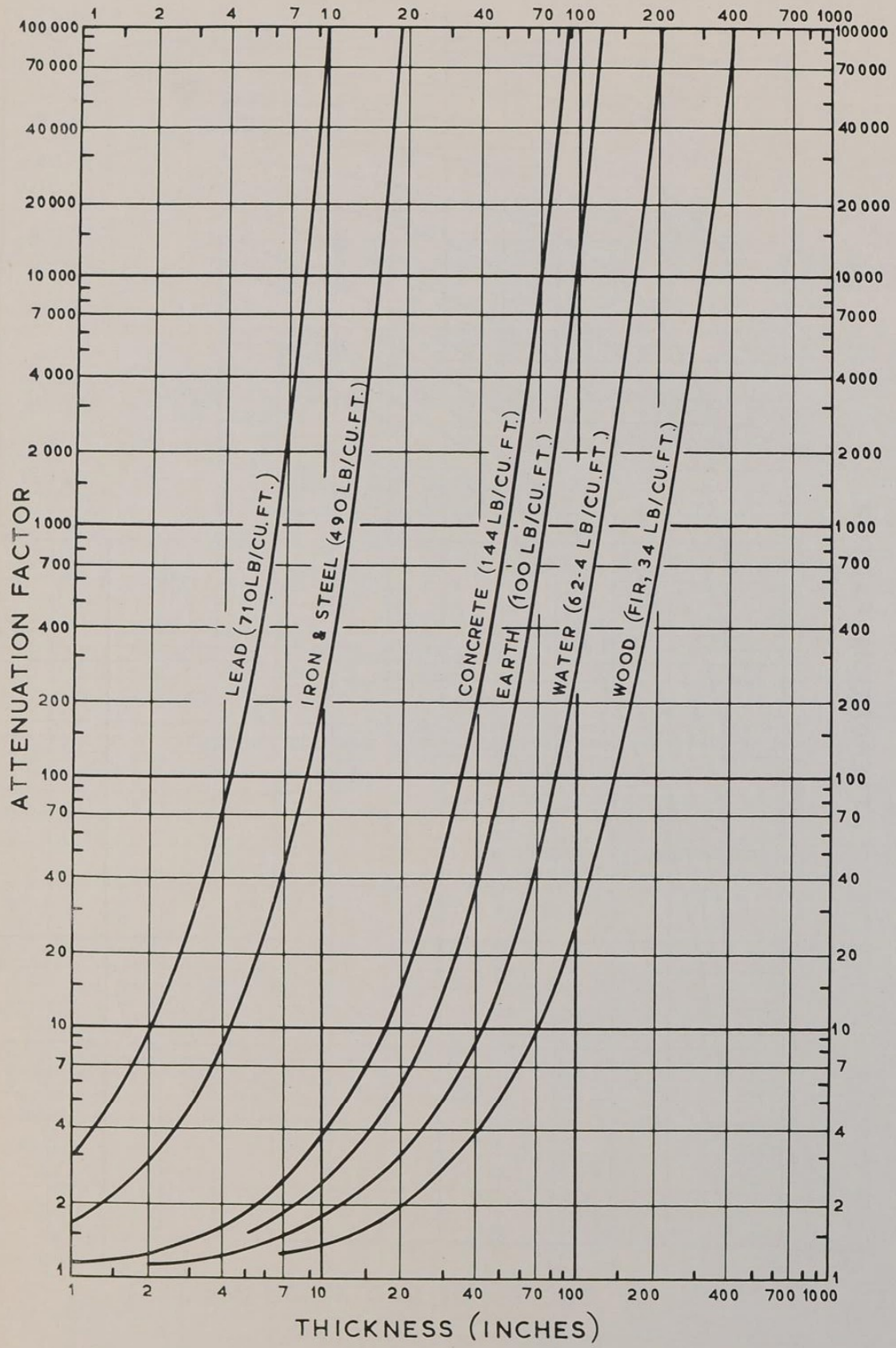

ATTENUATION OF INITIAL GAMMA RADIATION

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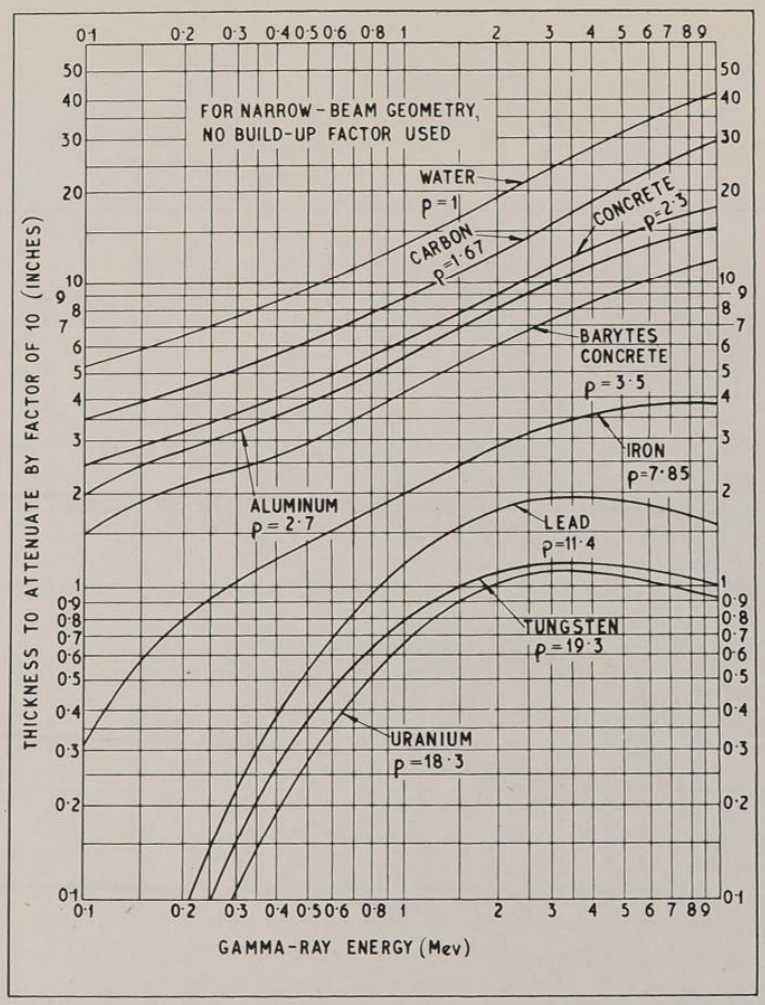
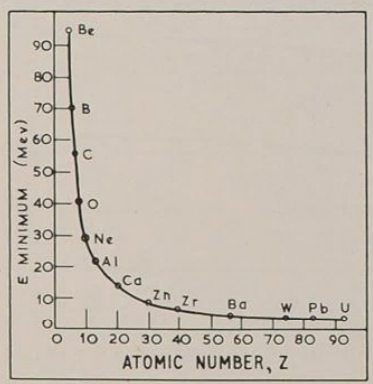
FIGURE 2

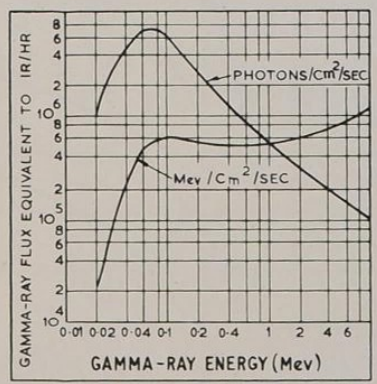
UNCLASSIFIED



A. THICKNESS TO ATTENUATE NARROW BEAM OF GAMMA-RAYS BY A FACTOR OF 10



B. ENERGY AT WHICH NARROW-BEAM ABSORPTION COEFFICIENTS ARE A MINIMUM



C. GAMMA-RAY FLUX EQUIVALENT TO 1R/HR AS A FUNCTION OF GAMMA-RAY ENERGY

THE THICKNESS TO ATTENUATE BY A FACTOR OTHER THAN TEN MAY BE OBTAINED BY MULTIPLYING THE TENTH-VALUE THICKNESS BY THE COMMON LOGARITHM OF THE DESIRED FACTOR, E.G. HALF-VALUE THICKNESSES ARE $\log_{10} 2 = 0.3010$ TIMES TENTH-VALUE THICKNESSES.

TENTH-VALUE THICKNESSES FOR GAMMA-RAY ABSORPTION

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5.1.6 Shielding by some common structures

The shielding data for parallel beams of radiation falling on simple shields are only of limited value in dealing with the protection afforded by actual structures. A few results are available from trials of weapons in the kiloton range and these, together with the results of some theoretical studies, are given here:-

(i) Concrete cubicles

At Operation Hurricane (Reference (1)) a number of concrete cubicles were built and gamma ray attenuation measurements were made by means of film badges placed across each cubicle, all at a height of 6 ft. The concrete had a density of about 133 lb./cu.ft. and the cubicles had sides 12 ft. long and 12 ft. high. The following results were obtained:-

Wall thickness (inches)	No. of badges	Attenuation Factor	
		Average	Range
$6\frac{3}{4}$	4	0.16	0.15 - 0.20
$9\frac{3}{4}$	3	0.096	0.082 - 0.12
12	4	0.064	0.057 - 0.079

Further observations on the penetration of concrete slabs by initial gamma radiation were made at Operations Totem and Buffalo (see also Section 5.1.5 of this chapter). It would appear from the evidence available (Reference (2)) that the gamma radiation from Buffalo Round 1 was substantially harder than that from Totem Round 1. The Buffalo half-thickness was about $4\frac{3}{4}$ inches of concrete (or 51 lb./ft.^{2}) compared with the Totem half-thickness of about $1\frac{3}{4}$-$2\frac{1}{2}$ inches of concrete (or 20-29 lb./ft.^{2}). The American data summarized in Reference (5) are more nearly in accord with the Buffalo results.

(ii) Anderson Shelters

A limited amount of information on these shelters was obtained at Operation Hurricane (Reference (1)). Owing to the irregular shape of this type of shelter, and the impossibility of maintaining a constant soil coverage, the results vary from one shelter to another. On average however, it was found that the attenuation factor in that part of the shelter which was above ground was about 0.03, while for the underground part of the shelter the factor was about 0.02. The penetration of Anderson shelters by initial gamma radiation was also studied at Operation Buffalo (Reference (2)) but the results showed considerable variation. A mean attenuation factor of about 0.05 was obtained.

(iii) Trenches

The protection afforded by trenches has been studied by A.O.R.G. (Reference (3)), and information obtained from tests with slit trenches and circular holes at Operation Totem, has been reported (Reference (4)).

The protective value of a trench depends on several factors, such as depth, orientation, nature of soil, amount and type of cover, angle of elevation to the burst, and the position at which the dose is measured. Some average figures for trenches 6' x 2' x 4'6" deep have been taken from the A.O.R.G. Report (Reference (3)) and are shown in Figure 1. Some values for gamma attenuation factors for circular pits at Operation Totem (Reference (4)) are given in Table 1. These pits were 6 ft. deep and 4 ft. in diameter, and those designated 'closed' were completely covered by an 18 inch thick layer of sandbags. The dose measurements were made with film badges mounted at the

stated heights on the centre line of each hole.

TABLE 1

Gamma Attenuation Factors for Circular Pits at Operation Totem

Depth below surface (inches)	Distance from Ground Zero and Exterior Dose							
	1710 ft. (1100r)		2720 ft. (950r)		3760 ft. (110r)		6010 ft. (4.7r)	
	Open	Closed	Open	Closed	Open	Closed	Open	Closed
0	1.0	96	1.0	63	1.0	78	1.0	36
6	2.1	100	3.7	56	2.8	55	3.4	39
12	3.8	105	7.3	53	5.2	52	6.5	47
24	12	120	16	79	13	100	15	94
36	21	150	29	155	24	165	24	105
48	38	190	45	250	39	240	34	120
60	58	310	63	320	52	330	48	140
72	92	610	86	380	61	380	64	170

Information on initial gamma attenuation factors, from an American source (Reference (5)), is listed in Table 2.

TABLE 2

Attenuation Factors for Initial Gamma Radiation

Geometry	Attenuation Factor
Foxholes[a]	0.05 - 0.10
Underground - 3 ft.	.04 - .05
Frame House	.9
Basement	.05 - .5
Multistory building	
Upper	.9
Lower	.3 - .6
Blockhouse walls	
9 inches	.1
12 inches	.05 - .09
24 inches	.01 - .03
Shelter, partly above ground level	
with earth cover - 2 ft.	.02 - .04
with earth cover - 3 ft.	.01 - .02
Tanks: M-24, M-41; Tank Recov. Veh. M-51, M-74	.1 - .2
Tanks: M-26, M-47, M-48, T-43E1: Eng. Armd. Vehicles T-39E2	.05 - .15
$\frac{1}{4}$ ton Truck	1.0
$\frac{3}{4}$ ton Truck	1.0
$2\frac{1}{2}$ ton Truck	1.0
Armd. Inf. Veh. M-59, M-75 and SP Twin 40 mm Gun M-42	.2 - .5
SP 105 mm Howitzer M37	.4 - .6
Multiple Cal. .50 m.g. Motor Carriage M-16	.8 - 1.0
LVT (Landing Vehicle Tracked)	.5 - .9
Battleships and Large Carriers[b]	
15% of Crew	1.0
25% of Crew	.2
10% of Crew	.05
50% of Crew	.0005 - .005
Cruisers and Carriers[b]	
10% of Crew	1.0
20% of Crew	.5
30% of Crew	.1 - .3
40% of Crew	.005 - .1
Destroyers, Transports and Escort Carriers[b]	
10% of Crew	1.0
20% of Crew	.7
30% of Crew	.4
40% of Crew	.1 - .4

a No line-of-sight radiation received
b Crew at General Quarters

References

(1) A.W.R.E. Report No. T20/54

(2) A.W.R.E. Report No. T42/57

(3) Army Operational Research Group, Report No. 12/55

(4) A.W.R.E. Report No. T6/56

(5) Capabilities of Atomic Weapons. A.F.S.W.P. TM23-200(1957)
(Confidential/Discreet)

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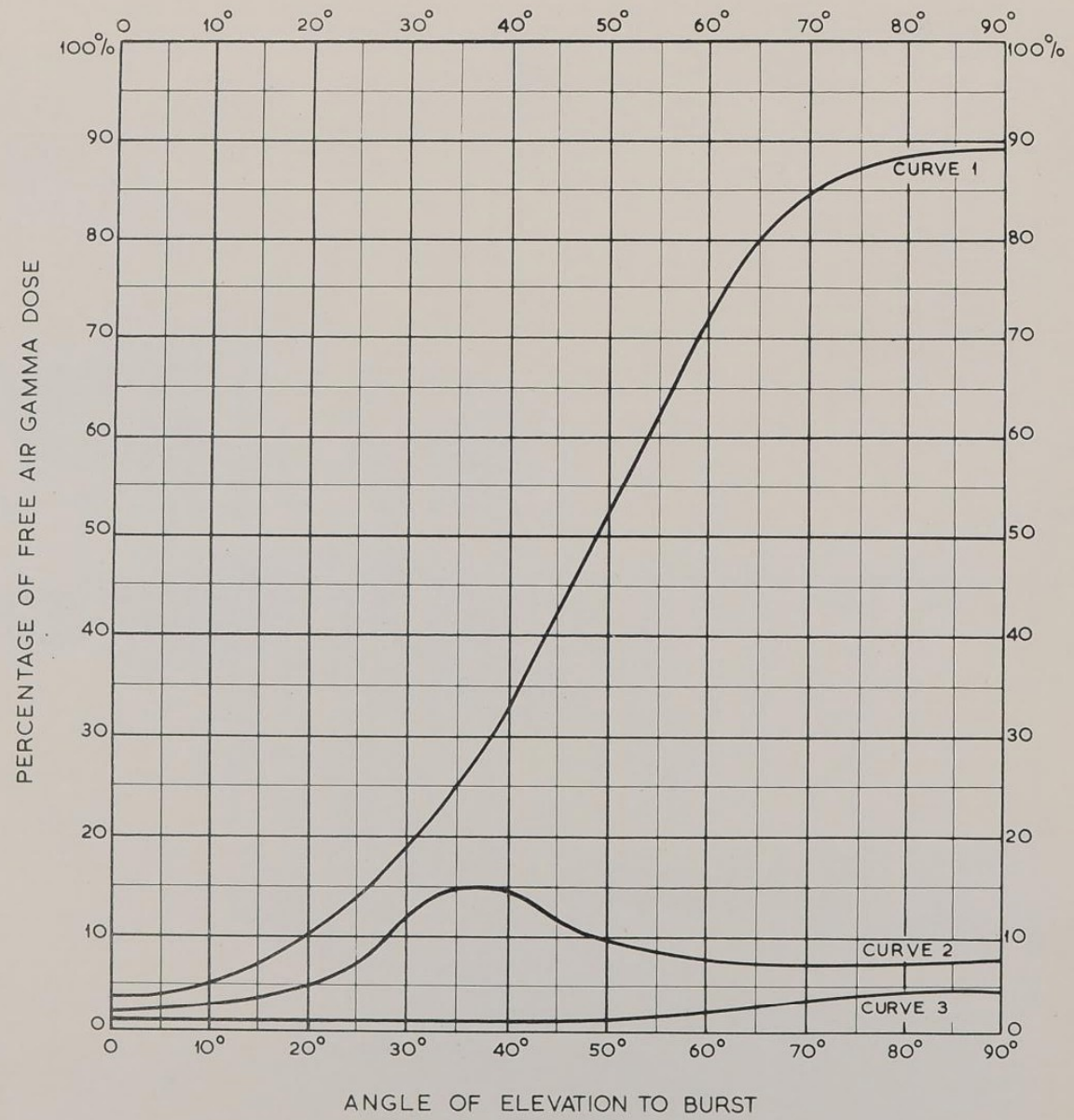
CHAPTER 5
SECTION 5.1.6
FIGURE 1

CURVE 1	OPEN TRENCHES
CURVE 2	TRENCHES WITH 18" RAISED EARTH COVER
CURVE 3	TRENCHES WITH 18" FLUSH EARTH COVER



SHIELDING VALUES FOR TRENCHES
AGAINST GAMMA RADIATION

5.2 Neutrons

5.2.1 Basic principles

Essentially all the neutrons accompanying a nuclear explosion are released either in the fission or fusion process. All of the neutrons from the latter source and over 99% of the fission neutrons are produced almost immediately, probably within less than a millionth of a second of the initiation of the explosion. These are referred to as the 'prompt' neutrons.

In addition, somewhat less than 1% of the fission neutrons, called the 'delayed' neutrons, are emitted subsequently. Since the majority of these 'delayed' neutrons are emitted within the first minute, however, they constitute part of the initial nuclear radiation. Some neutrons are also produced by the action of gamma rays of high energy on the nuclear bomb materials, but these make a very minor contribution and so can be ignored.

Neutrons bear no charge and so do not directly ionise the medium through which they are moving. Their mass is comparable to that of the lighter elements, and they may undergo strong interactions with nuclei. Because of these two properties, neutrons may cause ionisation indirectly (a) by elastic collisions, and (b) by capture by nuclei.

(a) Elastic collisions - In an elastic collision the neutron and the nucleus with which it collides may be considered to behave as rigid spheres. If the neutron is moving so fast compared with thermal velocities that the nucleus with which it collides may be treated as being at rest, the energy of this nucleus after the collision will be between 0 and E_{max}, where:

$$E_{max} = \frac{4A}{(A+1)^2} E \qquad (5.2.1)$$

E = The energy of the neutron before collision

A = The atomic weight of the nucleus.

For light elements the scattering is usually isotropic, and in this case the average energy of the nucleus will be $\frac{1}{2} E_{max}$. Thus, in an elastic collision a neutron with kinetic energy greater than about 1 Kev can impart enough energy to a light nucleus to enable that nucleus to ionise the material through which it moves. The density of ionisation caused by such a nucleus is very great and therefore its range will be very much shorter than that of an electron of the same energy (approximately $\frac{1}{100}$ for the H nucleus).

(b) Neutron capture - Any interaction between neutrons and nuclei other than elastic scattering is considered to proceed through the formation of a 'compound nucleus' made up of the incident neutron and the nucleus it has struck. This compound nucleus is invariably formed in an excited state and it may lose this excitation energy in a variety of ways, with corresponding end products.

(i) Inelastic scattering - The compound nucleus emits a neutron of energy less than that of the incident neutron, and a gamma-ray. This process can only occur if the energy of the incident neutron exceeds that of the first gamma emitting state of the target nucleus. This threshold energy effect is also shown by the capture processes involving charged particle emission. The process of inelastic scattering is denoted by $(n, n\gamma)$, where the symbol before the comma denotes the ingoing particle, and the symbols after the comma represent the outgoing particles.

(ii) Radiative capture (n,γ) - In this case a gamma-ray only is emitted after the neutron has been captured. This is the most common reaction between nuclei and thermal neutrons. Highly energetic gamma rays can be produced. The resulting nucleus, of increased atomic weight, may be unstable.

(iii) Charged particle emission - (n, q) - The particle emitted is usually either a proton (n, p) or an alpha particle (n,α); more rarely other light nuclei may be emitted. There are two important cases where charged particle emission may follow the absorption of a thermal neutron, namely N^{14} (n, p) and B^{10} (n,α). These charged particles will have a short range and be densely ionising. It should be noted that the nucleus remaining after (n,γ) or (n, q) may be radioactive.

The probability of occurrence and relative importance of these processes vary considerably with the energy of the neutrons and the composition of the material through which they are moving. In dealing with the effect of neutrons from a nuclear weapon on any target it is therefore necessary to know something of the neutron energy spectrum, that is the distribution of energy values among the neutrons, as well as of the composition of the target. Since the prompt neutron energies are fairly well known, it should be possible, in principle, to calculate the energy spectrum of the neutrons after penetrating the bomb materials. However, since these materials are not completely dispersed when the neutrons are emitted, the neutron spectrum depends on the detailed geometry of the bomb components at an extremely complex stage of the explosion. Variations in bomb design may therefore give rise to wide variations in the energy distribution and intensity of the neutron flux. Because of this, a theoretical solution is virtually impossible and one must resort to experiments.

It is, however, very difficult to measure the neutron spectrum from a nuclear explosion at distances of interest. The method at present adopted is to estimate the number of neutrons with energies above certain values by measuring the activity induced in suitably chosen targets which can be activated only by neutrons having energies above these values. The interpretation of the results obtained may give rise to difficulties.

Elastic and inelastic scattering eventually reduce the energy of all neutrone that are not absorbed to a level where they are in thermal equilibrium with the surrounding medium (thermal neutrons); at normal temperatures this energy is about 0.025 ev. At energies of this order the cross section for the (n,γ) process in many elements is large, and when the product nucleus is radioactive and has a suitable half-life (of the order of a few hours), targets of such elements provide a convenient method of estimating the number of 'thermalised' and 'nearly thermalised' neutrons reaching the target.

A detailed account of the mechanisms and problems of neutron shielding is given in Chapters 3 and 4 of Reference (1).

References

(1) "Radiation Shielding". B.T. Price, C.C. Horton, and K.T. Spinney. (Pergamon Press, 1957)

5.2.2 Yield and Energy Spectrum

The neutron flux in various energy bands, and the neutron dose, have been measured over a range of distances from nuclear weapons at a number of trials. Up to the present, British measurements of the neutron spectrum have been limited to assessing the numbers of neutrons reaching the target in two energy groups which are referred to as fast and slow neutrons. The number of fast neutrons is deduced from the activation of S^{32} by the (n,p) reaction which is considered to have a threshold at 2.5 Mev and yields P^{32}, a beta emitter with a half-life of 14.3 days. The number of slow neutrons, i.e. neutrons with energy below about 0.2 ev, is deduced from the activity induced in target materials in which an (n,γ) reaction produces a radioactive nucleus.

In order to estimate the number of neutrons with energies between 0.2 ev and 2.5 Mev the Americans have used detectors of U^{238} (which has a threshold for fission with neutrons at 1.5 Mev), Np^{237}, (fission threshold 0.7 Mev), and Pu^{239} in a boron shield, (fission threshold 100 ev). The results show that at distances greater than 1,500 feet from the explosion the proportion of neutrons in each of the energy bands is approximately the same for all distances and for all weapons, although the total flux decreases rapidly with increasing distance. This is illustrated in Figure 1 which is derived from data given for a 20 KT weapon in References (1) and (2). It gives the number of neutrons/cm^2 in each energy group reaching the groun as a function of distance from the explosion.

However, the external neutron yield per kiloton varies considerably with the design of the weapon. The extent of this variation in American weapons is shown in Figures 8 and 9, Chapter 3, Section 3.1, which show the upper and lower limits of neutron dose per kiloton as a function of distance and are taken from Reference (3). A similar spread is shown in the values obtained on British tests of weapons in the kiloton range (Reference (4)). According to Reference (5) the values given in Figure 1 apply to a low neutron yield weapon.

References

(1) The Effects of Atomic Weapons, page 243, U.S.A.E.C., 1950.

(2) The Effects of Nuclear Weapons, page 385, U.S.A.E.C., 1957.

(3) Capabilities of Atomic Weapons, A.F.S.W.P. TM.23-200 (1955) (Confidential/Discreet)

(4) A.W.R.E. Report No. T59/57.

(5) A.W.R.E. Report No. E5/54.

7.7.2. Protective clothing

Radioactive dust may be encountered during a period of fallout, or later, in association with contaminated ground. The radiation from the airborne dust will always be small, and in the latter instance negligible in comparison with that from the ground. Wearable clothing has no effect on the gamma intensity, although it may somewhat reduce the beta intensity. Although clothing will therefore give little direct protection, it is of value in acting as a barrier to dust contamination which can be removed after the period of exposure and destroyed or decontaminated. By this means the need to decontaminate exposed parts of the body and the ordinary clothing can be avoided.

Requirements

These may be considered under the following headings:-

(1) Resistance to penetration by dust

(2) Low dust retention

(3) Ease of decontamination

(4) Good comfort and wearability

(5) Low cost and avoidance of use of scarce materials

(6) Rain or showerproofness

(7) Durability.

The individual requirements for protective clothing are inter-related, and the best practical garments are those which afford the best compromise. The greatest resistance to penetration will obviously be afforded by impermeable materials whose smooth surfaces also retain very little dust, and are usually (but not necessarily) relatively easy to decontaminate; such materials may cause severe thermal stress and be wearable only for short periods, particularly when heavy work is being performed. Permeable fabrics, if made smooth and fairly close-woven, can give good protection, and are much cooler, but would probably be inadequate against wet fallout.

Materials

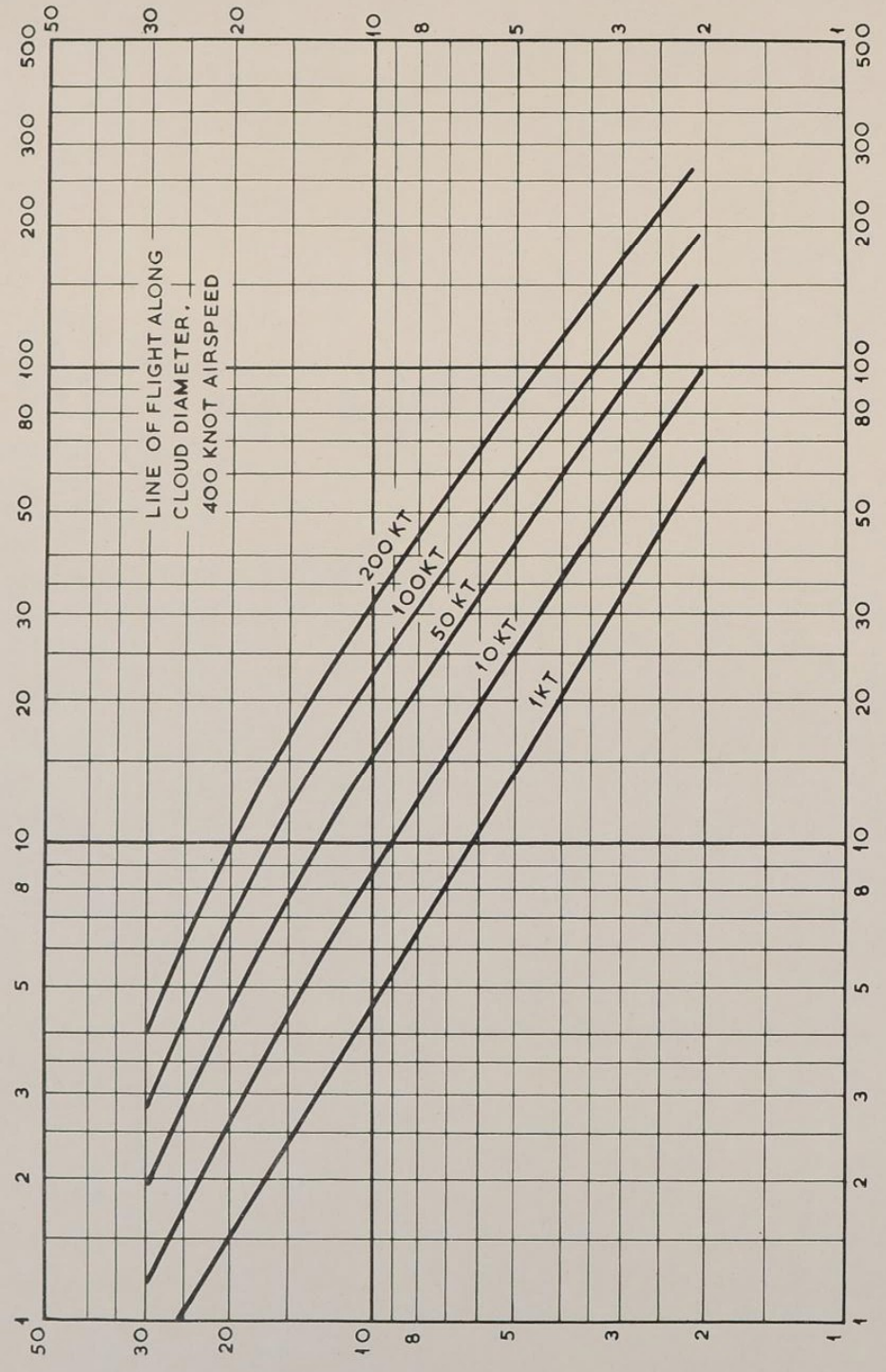
Information regarding the suitability of different materials for use in protective garmetnts, is scanty. In the impermeable class, P.V.C. and particularly rubber, are difficult to decontaminate; polythene and polystryrene are the best of the commonly available materials. Permeable fabrics vary considerably, both in the degree of take-up and ease of decontamination. Terylene and nylon fabrics are better in both respects than those made from natural fibres. Wool retains more dust than cotton, but is more easily decontaminated. Improved methods of decontamination may be more effective for one material than for another, and thus may change the order of preference. However, it is most likely that other factors than dust take-up and ease of decontamination will continue to determine the materials used.

Three distinct conditions can be envisaged which would have a bearing on the protective clothing requirement:-

(1) Exposure to wet fallout

(2) Exposure to dry fallout

(3) Heavy or moderate work under dust-raising conditions in a contaminated area.



RADIATION DOSE RECEIVED FROM FLYING THROUGH AN ATOMIC CLOUD

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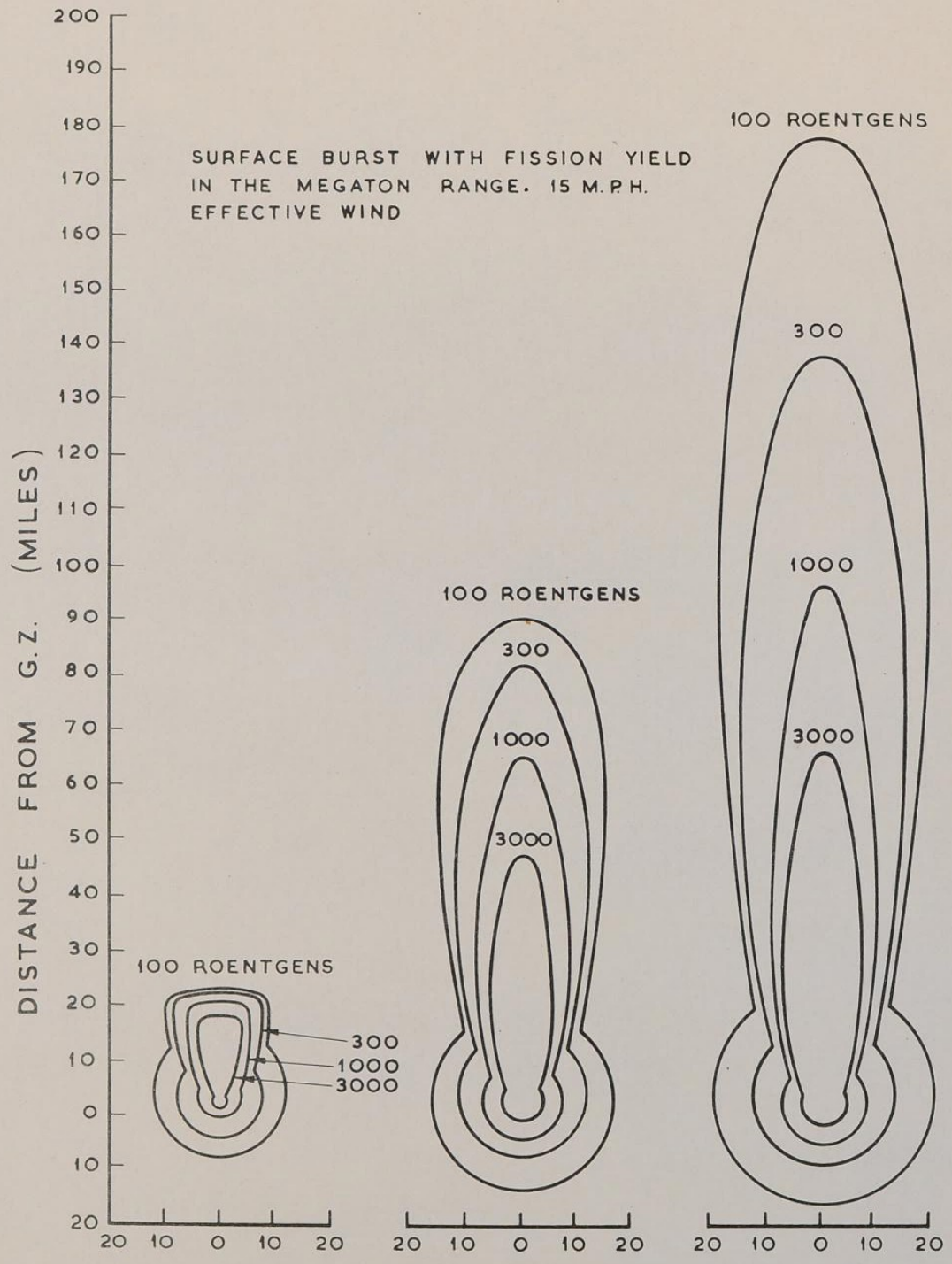
FIGURE 5



TOTAL (ACCUMULATED) DOSE CONTOURS FROM FALLOUT-MEGATON SURFACE BURST

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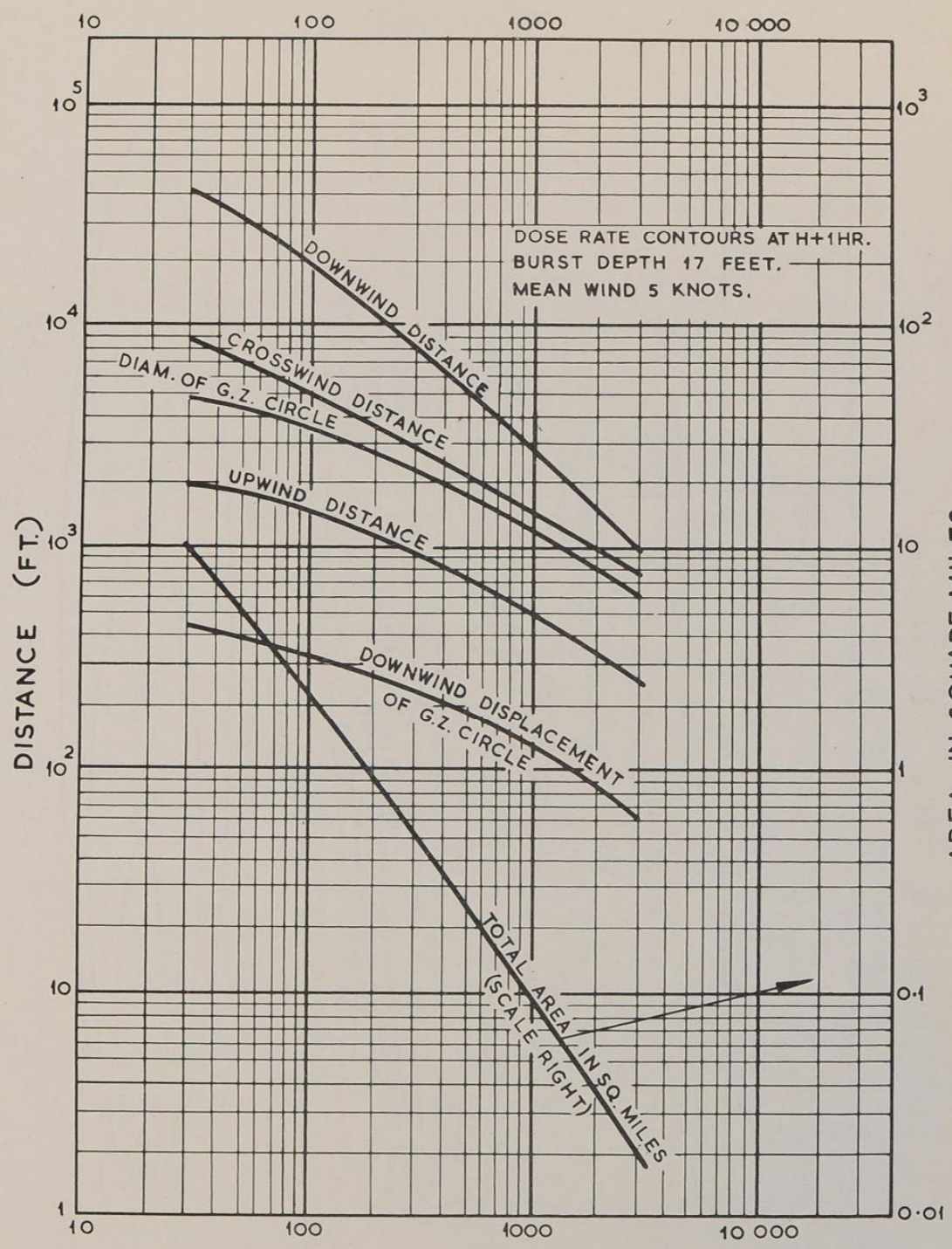
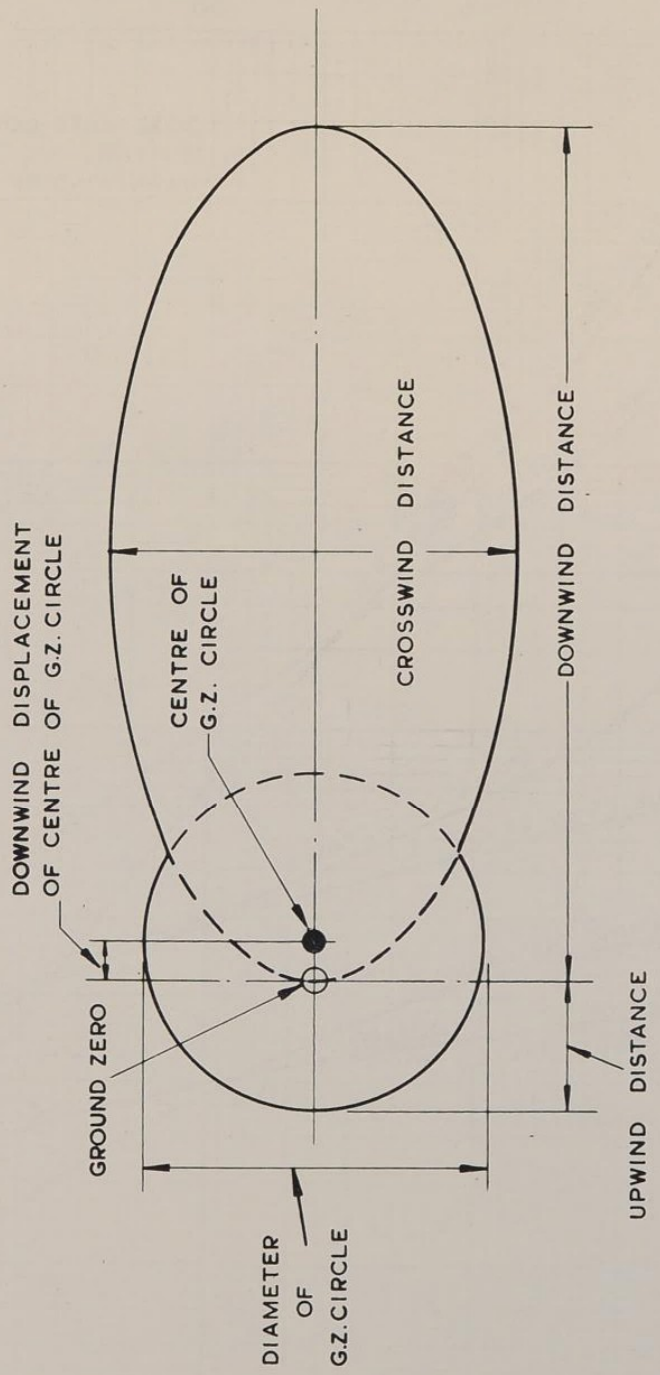
FIGURE 3



DIMENSIONS FOR CONTAMINATION PATTERNS
1KT UNDERGROUND BURST



GENERALISED FALLOUT PATTERN

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FIGURE 2

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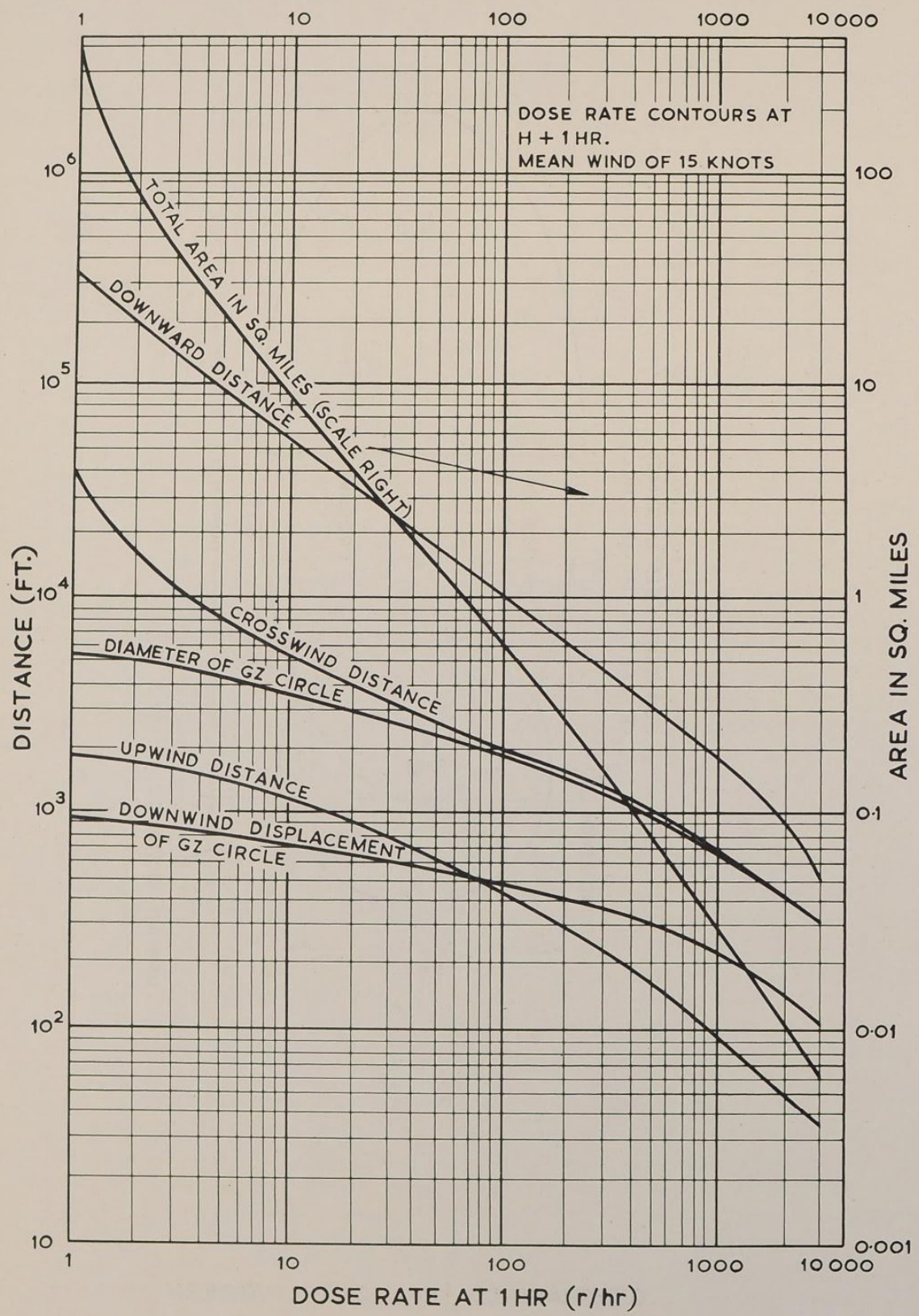

DIMENSIONS FOR CONTAMINATION PATTERNS
1 KT SURFACE BURST

TABLE 1

Calculated Radiation Doses at Two Locations in Ronglap Atoll from Fallout Following the March 1st, 1954, Test at Bikini

Exposure period after the explosion	Accumulated dose in this period (roentgens)	
	Inhabited location	Uninhabited location
First 36 hours	140	2,150
36 hours to one week	101	1,310
One week to one month	73	950
One month to one year	83	1,080
Total to one year	397	5,490
One year to infinity	about 129	1,680

The following observations on the close-in time of arrival of fallout and the build-up of activity, are due to Shelton (Reference (3)).

Fallout from an overland surface burst of about a megaton will begin to arrive on the ground over an area the order of the size of the visible cloud, almost like a blanket, at about 15-20 minutes following detonation. Fallout from a shot of the order of a megaton on a barge in water will begin to arrive at the surface after about 30-40 minutes. These times of arrival of the first fallout are related to particle size, the land shot fallout having the larger median particle size.

A law relating the time of arrival of fallout and peak radiation intensity, has been stated by Shelton as follows:-

> If fallout begins at a given place at t_a (hours) after detonation, then the peak dose-rate will be at $2t_a$(hours) and fallout will cease at about $5t_a^{0.7}$ (where t_a in the latter case has been less than, or equal to about 13 hours).

This leads to the conclusion that the time of peak activity approaches the time that fallout ceases as the time of arrival increases.

Reference should be made to Chapter 3, Section 3.2, for details of the critical doses and contamination levels from residual radiations, and also to Chapter 7, Section 7.6, which discusses the hazards from fallout.

References

(1) Hicks, E.P. "United Kingdom Method of Predicting Fallout Beyond 10 miles - Criteria used at Maralinga". Tripartite Conference on The Effects of Atomic Weapons, 1957.

(2) Effects of Atomic Weapons, U.S.A.E.C. 1957, Chapter 9, pp 408-427.

(3) Shelton, F.H. - "The Physical Aspects of Fallout". Tripartite Conference on The Effects of Atomic Weapons, 1957.

(4) Residual Contamination of Plants, Animals, Soil and Water of the Marshall Islands, Two Years' following Operation Castle Fallout. U.S.N. R.D.L.- 455. NS-081-001. 15th August, 1956. (Discreet/Military Use Only).

7.5. Areas of Contamination.

Contamination from long-range fallout is world wide, but owing to its wide dispersal and slow rate of deposition it cannot be attributed to any particular incident; it arises from the gradual build-up of deposits from an increasing number of nuclear explosions. Similarly, the hazards associated with it will be due to the slow cumulative build-up of dangerous radioactive isotopes of long half-life, e.g. Strontium 90. The contamination which can be associated with a particular incident will be that arising from medium and short-range fallout, and it is the areas of such contamination that are discussed here.

As the hazards from this type of contamination arise mainly from the external radiation, it is customary to express the areas of contamination in terms of radiation dose-rates.

Because of the complex and variable factors which influence the deposition patterns it is virtually impossible to predict the detailed pattern of contamination arising from any particular explosion. However, by recourse to an idealised fallout pattern it is possible to derive nominal fallout patterns, which can then be modified in the light of practical experience. For this purpose the complicated wind structure extending from the ground to the top of the cloud is replaced by a single mean wind. The apparent velocity of the mean wind is roughly determined by averaging the scalar velocities of the resultant winds from all altitudes between the top and bottom of the stabilised bomb cloud. A resultant wind vector for a given altitude is the vector average for all wind vectors from that altitude down to the surface. Through the concept of a single mean wind, and the use of appropriate scaling factors, it is possible to compute the idealised fallout pattern corresponding to any circumstances.

A more elaborate method of predicting fallout beyond ten miles has been developed by Hicks (Reference (1)) and used at British Trials at Maralinga.

The general features of the fallout pattern are as follows. Ground contours of equal gamma dose rate consist of two overlapping curves,

(a) Ground Zero circles whose centres are displaced a short distance downwind of Ground Zero.

(b) Down-wind ellipses having one vertex at Ground Zero and major axis extending in a down-wind direction.

These features are illustrated in Figure 1.

For a given explosion, the dimensions of the Ground Zero circles and down-wind ellipses are determined by the dose-rate of which these curves are the contour. The data are thus conveniently expressed graphically, the dimensions and areas of the contamination contours being plotted against dose rate, usually referred to a time of H + 1 hours (one hour after the explosion).

The dimensions of the idealised dose-rate contours for a 1 KT surface burst fired in a mean wind of 15 knots, are given in Figure 2 (taken from M.E.A.W., Figure 6.3.1.). Corresponding data for surface bursts of other yields and wind speeds can be obtained from the following scaling laws (reference M.E.A.W, Data Sheet 6.3.3.).

(i) Variation with weapon yield. Multiply all linear dimensions and also the value of the dose rate by $W^{\frac{1}{3}}$, where W is the total yield in kilotons.

(ii) Variations with wind speed. Multiply the down-wind displacement of the Ground Zero circle and the down-wind length of the ellipse by the cube root of the wind speed ratio, i.e. by $\left(\frac{S}{15}\right)^{\frac{1}{3}}$

where S is the wind speed in knots. Divide the cross-wind breadth of the ellipse by the cube root of the wind speed ratio. The radius of the Ground Zero circle, areas of both circle and ellipse, and the value of the dose-rate on these contours, are all unchanged.

Another factor which can affect the fallout dose-rate contours is the degree of contact between the fireball and the ground. Contamination data for a 1 KT weapon exploded underground at a depth of 17 ft. in a 5-knot wind, are given in Figure 3, (taken from M.E.A.W, Figure 6.3.2.). The scaling laws stated in the previous paragraph give corresponding data for other wind speeds and yields of weapon exploded underground at a scaled depth of 17 $W^{\frac{1}{3}}$ ft.

Some indication of the manner in which the fallout pattern develops over a large area during a period of several hours following a nuclear surface burst of high yield is illustrated by Figures 4 and 5, taken from Reference (2). The mean wind velocity was taken as 15 miles per hour. Figure 4 shows a number of contours for certain arbitrary values of the dose-rate, as would actually be observed on the ground, at 1, 6 and 18 hours respectively after the explosion. A series of total or accumulated dose contours for the same times are given in Figure 5. It will be appreciated that the various dose-rates and doses change gradually from one contour line to the next. Similarly, the last contour line shown does not represent the limit of the contamination, since the dose-rate and dose will fall off steadily over a greater distance.

In general, at any given location at a distance from a surface burst, some time will elapse before the fallout arrives. This time will depend on the distance from Ground Zero, the time taken from the particles to descend to earth, and the mean wind velocity. When the fallout first arrives the exposure dose-rate is small, but it increases steadily as more and more fallout descends. In a few hours the fallout will be mainly (although not absolutely) complete, and then the radioactive decay of the fission products will be accompanied by a steady decrease in the dose-rate. Until the fallout commences, the total dose will be zero, but after its arrival, the accumulated radiation dose will increase continuously, at first rapidly and then somewhat more slowly, over a long period of time, extending for many months and even years (see Table 1, taken from Reference (2)).

6.4. Shielding by Some Common Structures

Measurements of the protection afforded by model houses against residual radiation were obtained at Operation Buffalo, and are reported in Reference (1).

Calculations on the shielding value of slit trenches against nuclear radiations are given in Reference (2).

Some measure of protection to roadways and open areas may be given by the erection of suitable earth barriers. This is discussed in Chapter 8, Section 8.3.6.

The protection afforded by a building or shelter against gamma-radiation from fallout may be expressed as the "protective factor". This is defined as the factor by which the dose rate received by a person in the building is reduced, compared with that received by a person standing in the open, or more accurately, on an infinite flat plane.

Two main difficulties arise in any attempt to calculate accurately the protective factors of buildings and shelters in general. The first difficulty is the complexity of the geometry involved (owing to the presence of doors, windows, chimney breasts, etc.) and the second concerns the uncertainty of the actual distribution of fallout material on the roof and walls of the building. Irregularities in fallout distribution on these areas are likely to arise from the slope and nature of the surface, and also from the effects of wind and weather.

A simple and rapid method of making a rough assessment of the protective factors of buildings and shelters is given in Reference (3). The basis of this scheme is to carry out the initial calculation in terms of an arbitrary "points scheme", awarding 1,000 points to a completely unprotected location (i.e. an infinite flat plane) and reducing the points for other situations in direct proportion to their protective factors. Thus, once the "points" value of a particular building have been calculated, its protective factor is given by:-

$$\text{Protective factor} = \frac{1{,}000}{\text{"Points" value}}$$

Separate consideration is given, and appropriate "points" calculated, for the radiation coming from each of five directions, that is, from the roof and the four walls. For each of these directions the "geometrical" points are first determined, that is the points which derive solely from the distance factor and depend on the size and height of the building. These "geometrical" points are then multiplied by the attenuation fraction resulting from the shielding material between the shelter and the fallout, to give the total roof or wall points as the case may be. These five sets of points are then added up to give the final value for the accommodation.

An assessment of the accuracy of the method has been obtained by comparing calculated values for protective factors with those given by field experiments using radioactive sources. It is concluded that:-

(i) Where the geometry of the shelter is simple (e.g. a brick surface shelter) results given by the points scheme should not be in error by more than 50 percent, and may be considerably better.

(ii) For complicated structures (e.g. the ground floor of a 19th century Government building), results given by the points scheme may be in error by a factor of 3 or 4. In these complicated cases the points scheme tends to under-estimate the protection given, so that results given by this scheme should be at least on the safe side.

See Reference (4) for the published version of this technique, with worked examples.

References

(1) Tripartite Conference Report TCR 7/57 by A.M. Western (Confidential) (To be published later as an A.W.R.E. Report).

(2) A.O.R.G. Report No. 12/55 - "The Protective Value to Personnel of Slit Trenches against Thermal and Gamma Radiation Effects of Nuclear Explosions. (Secret/U.K. Eyes Only)

(3) Home Office Report CD/SA 68, 1956 - "Protection Against Gamma-Radiation from Fallout" (Confidential)

(4) Home Office Publication "Assessment of the Protection Afforded by Buildings against Gamma-Radiation from Fallout", (1957). H.M.S.O.

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PART VII
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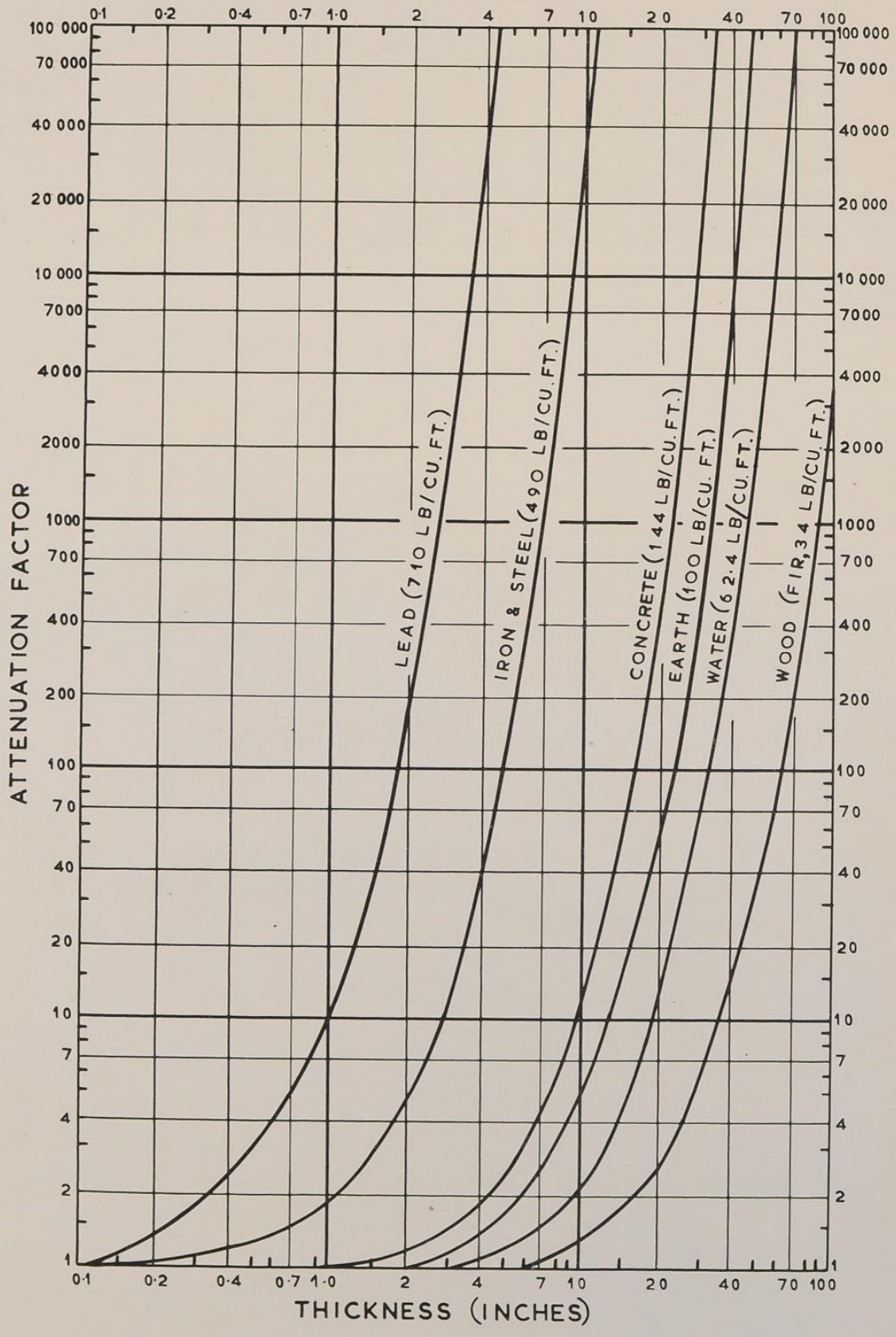
FIGURE 1



ATTENUATION OF FISSION PRODUCT RADIATION

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6.3. Shielding from Residual Gamma-Radiation

The mechanism by which this radiation interacts with matter are the same as those described for initial gamma-radiation. Attenuation factors for various shields can be calculated from Figure 1, Section 5.1.4 of Chapter 5, on Shielding against initial gamma-radiation, but a lower mean energy will be appropriate. In this matter there is no evidence of any difference between kiloton weapons and megaton weapons. An average energy of 0.7 Mev has been recommended (Reference (1) p.402), but calculation (Reference (2)) suggests that for thick shields (greater than 9 inches of concrete) 1 Mev may be better when calculations are done by the modified upper limit method (Reference(3)). The low energies of the radiation increase the complications of calculating from first principles because of air scattering effects. Figure 1 taken from Reference (1) p.403, gives values for the attenuation of residual gamma-radiation by various materials. It should be noted however that these curves (which are similar to those given in Figure 70 of Reference (4)), do not agree with the half-thickness values quoted in Table 9.35 page 402, of Reference (1). For example, the half-value thickness for concrete in the figure is read off as 4.5 inches, whereas in Table 9.35 it is given as 2.2 inches. In British Trials a figure of 2.3 inches was obtained, and the U.S. figure of 4.5 inches would therefore seem to be an error.

References

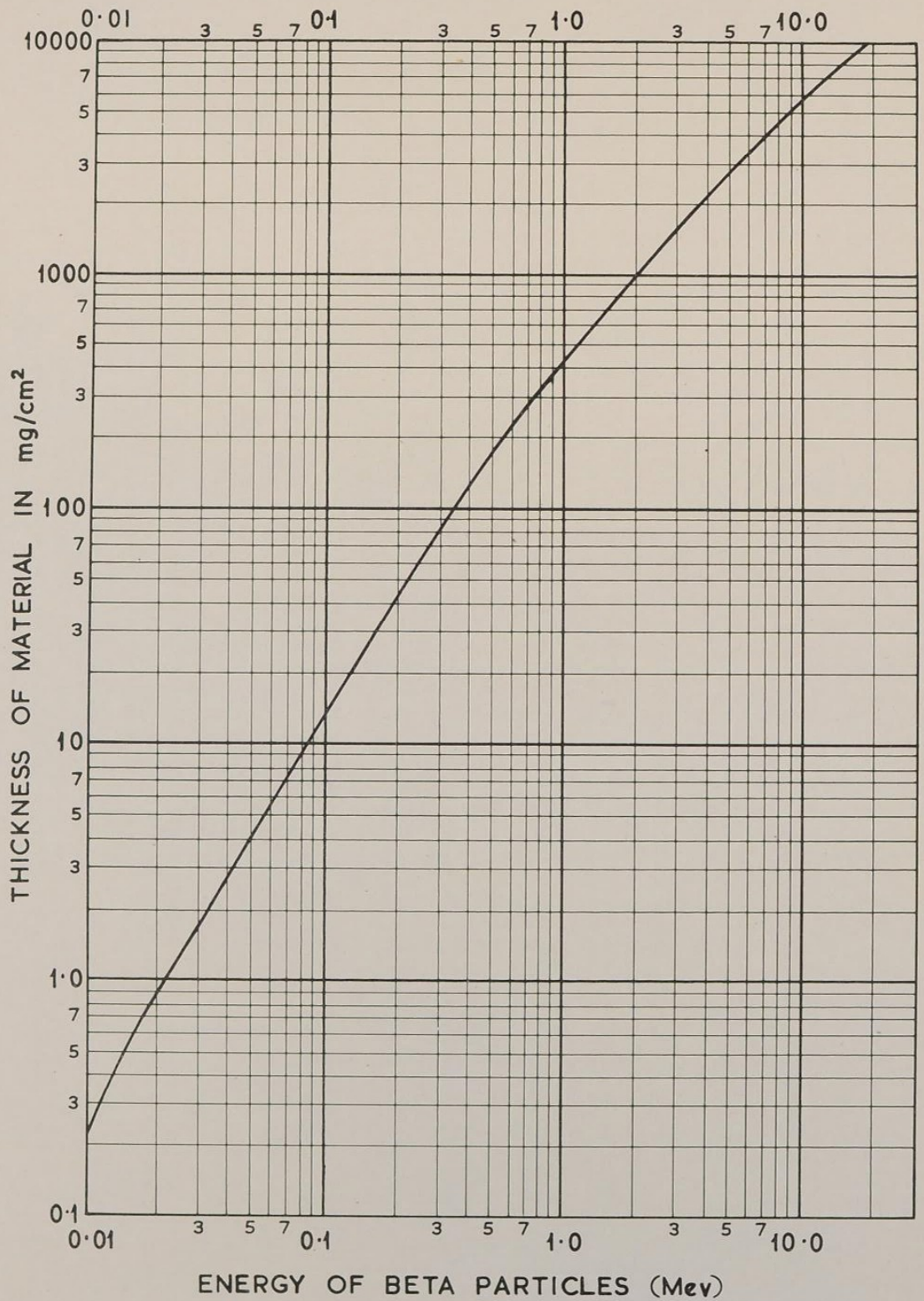
(1) The Effects of Nuclear Weapons, U.S. Atomic Energy Commission, 1957.

(2) Home Office Report CD/SA 62, 1955.

(3) Ministry of Supply, H.E.R. Report No. H13/51, 1951, "Tables for the Solution of Gamma-Ray Shielding Problems". (Restricted)

(4) Capabilities of Atomic Weapons, A.F.S.W.P. TM23-200 (1955) (Confidential/Atomic)

PART VII
CHAPTER 6
SECTION 6.2
FIGURE 1



RANGES OF BETA PARTICLES

6.2. Shielding from Residual Beta-Radiation

The ranges of beta particles in matter are shown in Figure 1. Except in the early stages after the explosion (up to an hour or two), there are no radioactive explosion products emitting beta particles of more than about 3 Mev energy and most of them emit beta particles of 2 Mev or less. Study of Figure 1 shows that shielding against beta particles is quite an easy matter, and most ordinary structures (buildings, aircraft, vehicles, thick clothing, etc.) are enough to keep out all or most of the beta particles from explosion products. Of course, further protection may be needed against beta emitting substances which may drift or be blown through gaps in structures such as windows, ventilators, etc.

5.2.6 Neutron absorption processes

A neutron in a narrow parallel beam of neutrons passing through an absorber may be removed from the beam by elastic scattering or by capture. If σ_t is the cross section (in cm^2) of a nucleus for the removal of a neutron from the beam in any way, and N is the number of nuclei/cm^3, the number of neutrons (I_x) left in the beam after penetrating a distance x cm, is:

$$I_x = I_o e^{-N\sigma_t x} = I_o e^{-\mu_t x} = I_o e^{-\frac{x}{\lambda}} \qquad (5.2.2)$$

where I_o = number of neutrons in the beam at distance x = o

$\mu_t = N\sigma_t$, is the narrow beam absorption coefficient (cm^{-1})

$\lambda = \frac{1}{\mu}$, is the mean free path (cm)..

Nuclear radii are of the order of 10^{-13} to 10^{-12} cm, and it is therefore convenient to express σ_t (which geometrically we would expect to be approximately Πr^2) in barns, where 1 barn = 1b = 10^{-24} cm^2.

The situation described above corresponds to narrow beam absorption; in practice we usually have to deal with situations corresponding to broad beam absorption, where neutrons scattered out of the beam but not absorbed, must also be considered. These can be formally allowed for (as in the gemma-ray case) by introducing a build-up factor, B [x, g(E), M] which will be a function of the distance penetrated (x), the energy distribution of the incident neutrons g(E), and the composition of the absorber (M). In view of the complex way in which the probability of neutron absorption processes depend on the energy of the neutron and the nature of the absorber, it is not generally feasible to deduce the build-up factor analytically. Qualitatively it can be seen that shields composed of elements in which elastic and inelastic scattering predominate will have large build-up factors, whereas any other type of interaction will tend to reduce it. In this connection it should be noted that radiative capture, although it reduces the neutron flux, results in gamma-rays which in many cases are more dangerous than the neutrons producing them.

Neutron cross sections do not show a regular variation with neutron energy and atomic number of the target, but some general trends are observable:

(a) The elastic scattering cr ss section increases with atomic weight (A) approximately as $A^{\frac{2}{3}}$ (as would be expected if nuclear matter had a constant density), and decreases with increasing energy. The importance of this process for shielding purposes is that it results in a slowing down of fast neutrons. For this to occur with a small number of collisions, A should be small (see Equation 5.2.1.).

(b) The cross section for any other process depends on two factors:-

(i) σ_c, the cross section for compound nucleus formation;

(ii) P_i, the probability that the compound nucleus will decay by process i.

Hence σ_i, the cross section for the process i, is $\sigma_i = \sigma_c . P_i$

5.2.4 Lethal dose of neutrons

The lethality of any radiation is described in terms of the dose which would be responsible for the death of 50 per cent of the exposed population. This dose is referred to as the 50 per cent lethal dose, or LD-50.

The LD-50 of neutrons for man depends on the energy of the neutrons, but there is some doubt as to the extent of this dependence. In Reference (1) it is stated that the generally accepted values of the lethal doses of slow (less than 0.2 ev) and fast (greater than 3 Mev) neutrons are 5×10^{11} neutrons/cm^2 and 10^{11} neutrons/cm^2 respectively. Marley (Reference (2)) takes 4×10^{11} neutrons/cm^2 and 10^{10} neutrons/cm^2 as the LD-50s for these two groups. Cave (Reference (3)), assuming that the lethal dose creates in the body an amount of ionisation biologically equivalent to that created by the lethal dose of gamma radiation (400r), arrives at the dependence of lethal dose on energy shown in column 2 of Table 1. Account is taken, both of the high energy protons from neutron collisions, and of the capture gammas. These values are based on a relative biological efficiency (r.b.e.) for fast protons of 6.5, i.e. it is considered that a given amount of energy released in tissue by fast protons is biologically equivalent to 6.5 times that amount of energy released by gamma-rays. It is now thought that this is too high for acute exposures and values between ~~1~~ 1.4 (Reference (4)) and 0.5 (Reference (5)) have been suggested for this case. Column 3 of Table 1 results from Cave's data when 1.3 is taken as the r.b.e. of fast protons.

TABLE 1

Relation between Neutron Energy and Lethal Dose

Neutron Energy	LD-50 (Neutrons/cm^2) (Proton r.b.e. = 6.5)	LD-50 (Neutrons/cm^2) (Proton r.b.e. = 1.3)
Thermal	1.6×10^{12}	1.6×10^{12}
1 Kev	1.8×10^{12}	1.8×10^{12}
3 Kev	1.7×10^{12}	1.8×10^{12}
10 Kev	1.4×10^{12}	1.6×10^{12}
30 Kev	9.2×10^{11}	1.5×10^{12}
100 Kev	4.1×10^{11}	1.1×10^{12}
300 Kev	1.6×10^{11}	5.9×10^{11}
1.0 Mev	5.0×10^{10}	2.2×10^{11}
3.0 Mev	1.6×10^{10}	8.2×10^{10}

References

(1) The Effects of Atomic Weapons, U.S.A.E.C., 1950

(2) A.E.R.E. Report No. HP/R.422

(3) L. Cave, British Journal of Radiology, Vol. 27, page 273 (1954)

(4) The Effects of Nuclear Weapons P.363, U.S.A.E.C., 1957

(5) Radiological Hazard Evaluation, U.S.N.R.D.L., 1957.

5.2.3 Angular Distribution at the Target

Very few measurements of the angular distribution of neutrons at the target have been reported. Western (Reference (1)) found that a thick wall 18 feet long by $7\frac{1}{2}$ feet high reduced the fast neutron flux to between 13% and 23%, showing that at least this part of the flux is due to scattered neutrons.

It is generally considered (e.g. see Reference (2)) that the distribution of slow neutrons is isotropic at distances from the detonation greater than 1,000 feet, as such neutrons have been scattered many times. The fast neutron angular distribution will, however, show a tendency for neutrons in this group to be incident from the direction of the explosion.

The angular distribution of neutrons at the target is considered by Mehl in Reference (3). At 900 metres from a nuclear test explosion less than one per cent of the flux in the energy interval between 0.7 and 1.5 Mev was from unscattered neutrons, yet the distribution was peaked quite strongly in the outward direction. As the neutrons were moderated to lower energies the distribution became more nearly isotropic, but it still peaked outwards. Preliminary results from this test are given in Table I.

TABLE 1

Angular Distribution of Neutron Flux at 900m from Weapon

θ°	Neutron Energy Band		
	200 eV/0.1 Mev	0.1/0.7 Mev	0.7/1.5 Mev
90° - 60°	0.85	0.38	0.18
60° - 30°	0.75	0.30	0.07
30° - -10°	0.60	0.20	0.03
-10° - -60°	0.52	0.16	0.02
-60° - -90°	0.45	0.14	0.015

θ = Angle from vertical in plane including the weapon, measured positive on side away from the weapon.

References

(1) Attenuation and Scattering of Initial Nuclear Radiation, Home Office Report CD/SA.85. (Confidential)

(2) The Effects of Nuclear Weapons, page 368, U.S.A.E.C., 1957.

(3) Scaling Neutron Flux with Altitude, C.R. Mehl. Tripartite Conference on Effects of Atomic Weapons (1957).

8.2. The Effect of Surface Conditions

The fallout from a nuclear explosion will settle in the form of particles of various sizes (reference Chapter 7), and the coarser particles will simply lie on the surfaces on which they come to rest, being removable by sweeping or suction. Finer dust particles may be attached to the surface by various means, such as adhesion by grease, or trapping by the pores in a rough surface.

Attachment by a form of ion-exchange is likely in all cases where the contaminant is soluble and may also occur in the case of surfaces which have available acid groups. These groups would be provided by organic surfaces such as paint, plastics and textiles, and also by glass. Ion-exchange between the acid groups and basic materials present in soluble or reactive contamination gives rise to strong adhesive forces. Chemical exchange may also occur on metal surfaces.

The results of tests to examine the influence of surface roughness, hardness and cleanliness on the contamination - decontamination behaviour of various materials (e.g. glass, tiles, metals, plastics, paints, etc.) have been reported in Reference (1).

The tests involved both a surface and underground burst, and the conclusions reached may be summarised as follows:-

(i) Surface roughness had no clearly defined effect on contaminability. Surface roughness did affect decontaminability by factors of 6-10 (for residual activity), the rough surfaces retaining more contamination than the smooth.

(ii) From data obtained with polyisobutylene it appeared that soft surfaces were contaminated to a greater degree than hard surfaces, and retained two to three times more activity (absolute) after decontamination, than hard surfaces.

(iii) Artificially soiled surfaces were more easily contaminated than clean surfaces by a factor of 2 to 7.5, but were decontaminated as well as, or better than clean surfaces.

(iv) Navy grey paint was from 1.5 to 12 times as contaminable as bare aluminium, glass, and chromium-nickel steel, but all these materials were readily decontaminated.

Results from further tests reported in Reference (1) show that contamination on horizontal surfaces was greater than on non-horizontal surfaces by factors up to 30 to 40. Vertical surfaces retained smaller particle sizes than inclined or horizontal surfaces. Very extensive measurements are reported in detail, and include a wide variety of surfaces and treatments.

References

(1) U.S. Armed Forces Special Weapons Project Report No. WT-400 "Operation Jangle".

Project 6.2 "Protection and Decontamination of Land Targets and Vehicles". (Secret)

8.3. General Decontamination Methods

8.3.1. Introduction

The method selected for decontamination will depend on the type of contamination, the extent of removal desired, the nature of the surface and the size of the object.

The methods available for the decontamination of objects, structures, roads, etc., may be considered under four headings:-

(i) Sweeping and vacuum cleaning.

(ii) Detergency

(iii) Chemical treatment

(iv) Surface removal.

In the case of land reclamation, special techniques requiring earth-moving equipment may be employed.

In all of these methods the techniques must be arranged to give the maximum possible protection to the operators, who will require adequate protective clothing, and suitable instruments for the measurement of radiation levels.

Since the object of decontamination work is to remove and confine the activity, an essential consideration is the disposal of contaminated waste. This must be conveyed or otherwise removed to a location where it does not constitute a danger.

8.3.2. Sweeping and vacuum cleaning

These are dry methods and in general tend to be more hazardous than wet processes. They are of use however, where the contaminant is mainly of an inert dusty nature. Vacuum cleaning is safer and more efficient than brushing, but the filters in commercial equipment do not ensure complete retention of radioactive dust.

A comparison between vacuum technique and high pressure hosing is given in Reference (1), and states that decontamination by vacuuming is relatively inefficient. Vacuuming at a decontamination rate of 40 sq.ft. per equipment-hour left a high residual contamination ranging from 9 to 84%. A high pressure water stream with detergent additive, on the other hand, cleaned a rough roof surface, slag or gravel finished, at a rate of approximately 600 sq.ft. per equipment-hour and left an average residual contamination of less than 2%.

It should be noted however that much will depend on the precise conditions, particularly particle size of the dust, and in many cases vacuum cleaning can be very efficient.

8.3.3. Detergency

This method consists of wet treatment of the surface with a detergent solution and is a relatively cheap and safe process. It is particularly effective in cleaning inert dusty contamination from smooth surfaces, but is less useful on surfaces where adsorption has occurred. Reactive contamination will respond to the use of a suitable detergent, and the nature of the detergent is of greater importance in this case.

The hazards from ingestion and inhalation of loose dust from a surface are considerably reduced by washing or spraying down the surface with detergent solution. In cases of more persistent contamination scrubbing or brushing will give improved results. The composition and application of various detergent solutions are given in Section 8.8, and the techniques for their use in Section 8.9.

8.3.4. Chemical treatment (complexing)

This treatment is carried out as a wet process using a solution of a "complexing" agent in conjunction with detergent action. The method is particularly suitable for removing reactive contamination from textiles, from smooth or thin porous surfaces, and from surfaces in general which do not respond satisfactorily to straight detergent. The complexing agent is a normally non-corrosive substance which will convert the contamination into a chemical form which is no longer retained by the surface. An example of such a substance is ethylene-diamine-tetra-acetic acid (EDTA). Details of this method and its application may be obtained from References (2) and (3).

8.3.5. Surface removal

This method may be carried out by a large variety of techniques, most of which are laborious but eventually very effective. Complete decontamination is usually possible.

Abrasive compositions are best applied under wet conditions together with the detergent and other additives. The composition of an efficient scouring paste is given in Section 8.8. Suitable chemical agents may be selected for specific types of surface, for example, acids for metal cleaning, and alkaline solution or suitable solvents for paint stripping.

Flame decontamination may also be considered as a surface removal technique. Reference (1) gives a description of a flame decontaminating unit (USNRDL Flaminator) incorporating a burner, a surface removal tool, and a vacuum pick-up system, which was tested on wood, asphalt and concrete surfaces contaminated by an underground burst atomic weapon. No apparent hazard is involved in the maintenance of the Flaminator, but during operations the operator must be protected by an efficient respirator.

8.3.6. Land reclamation

Since the contamination is mainly held in the superficial layer of soil, the radiation field from a contaminated natural land area may be reduced for limited sectors by standard methods of earth movement such as ploughing, harrowing, scraping and filling. The use of such surface techniques is described in Reference (1). It is stated that time, man-power and equipment requirements do not differ significantly from those that would apply in the absence of radioactive contamination. Tests were made following a surface burst, and the test area was plane and free from gulleys and surface irregularities, and covered to about 10% by sage brush from one to three feet high. The soil was a non-compacted, non-cohesive silty sand weighing about 150 lb./cu.ft. The moisture content, owing to rainfall before the weapon burst, was about 20% to a depth of 6 inches. It is stated that the radiation fields were reduced 70 - 90% through the use of standard earth-moving procedures and equipment. In the scraping operations, it is unnecessary to haul the spoil any further than the boundaries of the area to be treated, and this material should be spread in a layer two to four inches deep.

Owing to the shielding afforded by the equipment the operators receive from 60 - 70% less readiation dosage than unshielded personnel working in the same area at the same time. Internal hazards due to the presence of airborne activity during operations can be minimised by the use of standard protective clothing and full-face respirator. Contamination of operating equipment does not constitute a serious hazard. In general, equipment will pick up a maximum of 10% of the level of the field in which it operates. Decontamination to acceptable tolerance levels can be accomplished adequately with high pressure hoses.

Another method also described in Reference (1) is designed to give protection to personnel traversing or occupying a radioactively contaminated region, by interposing earth barriers between the radiation source and the area occupied. It was found that an earth wall 4.5 ft. high, on each side of a 30 ft. wide roadway, reduced the radiation field in the roadway by a factor of about 3.5.

The radiation intensity at the bottom of a fox hole and a trench was found to be less than that at 3 ft. above the ground by a factor of about 20.

A circular cleared area 180 ft. in diameter afforded a radiation reduction of a factor of 5, measured 3 ft. above the centre. It was determined that increases in the diameter of the clearing beyond 200 ft. did not afford any significantly greater reduction at the centre.

In comparing barrier and surface techniques, it was found that for a given amount of time, and using identical equipment, surface clearing yielded a greater maximum reduction in the radiation field (by a factor of 1.5) and produced approximately four times the working area produced by the barrier technique.

The recontamination of treated areas through wind action is relatively unpredictable on the basis of present knowledge.

References

(1) U.S. Armed Forces Special Weapons Project, Report No. WT-400, Operation 'Jangle'. Project 6.2 "Protection and Decontamination of Land Targets and Vehicles. (Secret)

(2) A.W.R.E. Report No. T22/57, Operation Buffalo, Decontamination Group Report, Parts 1-4. (Confidential)

(3) A.W.R.E. Report No. T63/57. The Handling, Servicing and Decontamination of Radioactive Aircraft. (Official Use Only)

8.4 Decontamination of Vehicles and Aircraft

Vehicles. Information regarding the contamination and decontamination of military vehicles at an atomic weapon test has been obtained from Reference (1). No difficult problems of decontamination were experienced, although vehicles operated in areas contaminated at levels up to 50r/hour, and included Weasels which operated on the lip of a surface burst crater $2\frac{1}{2}$ hours after the time of burst. These Weasels were monitored approximately 24 hours after the burst time and had a general level of contamination of 30 mr/hour. Their treads gave readings of 70 mr/hour, and the levels of activity in the personnel compartments were 10 mr/hour.

Tanks which were operated in the same areas one day after the surface explosion displayed activity levels two or three times background.

High levels of intensity (up to 13r/hour) were noted in the beds of vehicles used for transporting contaminated material from radioactive areas.

Soil properties influenced the degree of contamination, and it is believed that fine dry soil of the type present in the test area lessened the decontamination problem. Under wet conditions greater contamination of the vehicle occurs, although the dust hazard to the operators and the upper surface contamination of the vehicle is reduced.

It is recommended that vehicle decontamination procedures be based on the urgency of the situation and that the following emergency methods may be used by the vehicle operator.

(i) Dry sweeping or brushing of the vehicle, paying particular attention to the removal of as much dirt as possible from the cab.

(ii) Wiping with wet rags.

(iii) Brush scrubbing with water, or soap and water; if plentiful water is available more thorough decontamination could be achieved by hosing down with water and scrubbing.

(iv) Greasy or oily areas may be cleaned by petrol applied on brushes or rags, (water is ineffective in this case).

A detailed account of the decontamination of vehicles (3-ton trucks, 1-ton trucks, Landrovers, armoured scout cars, etc.) used at Operation Buffalo is given in Reference (2). Steam cleaning was found to be the quickest and most satisfactory method for extensive and greasy areas, e.g. engines, chassis and vehicle surfaces generally. A disadvantage in the use of steam was the lack of both control and visibility. High pressure hosing was a little slower, but more economical.

Aircraft. The decontamination of aircraft used at two British trials is reported in Reference (3) (Operation Mosaic) and Reference (2), (Operation Buffalo). It is noted in the latter reference that the contaminant, in contrast to ground fallout, appeared to be largely ionic and therefore required the use of complexing agents or barrier films for efficient removal. The initial levels were relatively uniform, suggesting absorption contamination mechanism rather than impaction. Reference (2) gives much detailed information on decontamination materials, procedures and man-power requirements for both vehicles and aircraft. A manual dealing exclusively with the handling, servicing and decontamination of radioactive aircraft

has been prepared (Reference (4)).

The effectiveness of various methods and cleaning compounds for the decontamination of aircraft contaminated by flying through an atomic cloud were investigated during the U.S. Operation Snapper, and are reported in Reference (5). Methods using brushing techniques were generally more effective than those not involving brushes. A solvent emulsion grease cleaning compound ("gunk" USAF Spec. 20015) was one of the most effective cleaning agents. Tests were made to determine the influence of surface condition, i.e. oiled, cleaned and polished, on contaminability. Surfaces coated with a light film of oil contaminated to a level six times as high as a clean clad aluminium surface. Polished surfaces became only half as contaminated as the clean clad aluminium.

Ultra-violet light and fluorescent zinc sulphide were employed to determine the possible contamination distribution throughout the interior of jet aircraft. Stepwise decontamination showed that the cockpit dose-rate could be reduced by approximately 60 per cent by decontaminating the air intake duct, tail pipe, and exterior surfaces. The remaining 40 per cent was contributed by the engine, residual contamination and contaminated places not accessible for decontamination. It should be noted however, that the effect of various measures on cockpit dose-rate will vary with the particular aircraft, and especially with the distance between the engines and the cockpit. Further, the validity of using zinc sulphide as a simulant is not established.

Regarding aircraft in general, a distinction should be made between aircraft contaminated on the ground and those contaminated in the air. Barrier films are effective in countering airborne contamination, by preventing contact between the soluble contaminant and the paint surface, (see References (2) and (4) for details).

References

(1) U.S. Armed Forces Special Weapons Project, Report No. WT-400, Operation Jangle. Project 6.2 - "Protection and Decontamination of Land Targets and Vehicles". (Secret)

(2) A.W.R.E. Report No. T22/57. Operation Buffalo, Decontamination Group Reports, Parts 1-4. (Confidential)

(3) A.W.R.E. Report No. T33/57. Operation Mosaic, Aircraft Decontamination (Confidential)

(4) A.W.R.E. Report No. T63/57. The Handling, Servicing, and Decontamination of Radioactive Aircraft. (Official Use Only)

(5) U.S. Armed Forces Special Weapons Project, Report WT-535 (March, 1953) Operation Snapper, Project 6.5 "Decontamination of Aircraft". (Confidential/Atomic)

8.5. Decontamination of Food and Water

Food protected by cans, dust-proof wrappings, or other effective measures should undergo little or no contamination from fallout. There is no practical means of salvaging food which has become radioactively contaminated.

Water supplies might be contaminated by radioactive dust falling on a reservoir or other source of supply. In surface waters the radioactive contaminants will tend to be adsorbed by suspended and colloidal matter and will eventually settle or be deposited on any available surface. Material carried out from a reservoir is likely to be removed by the normal water purification process, which usually includes sedimentation and filtration stages. Because of the absorptive properties of soil, underground sources of water such as springs and wells would usually be safe from contamination.

If a river or reservoir is seriously contaminated, and the water is not subjected to any purification processes, the water may be unfit for consumption for several days. Careful examination of the supply would be necessary, and it must be remembered that in this connection alpha and beta activity, as well as gamma, are very important.

Contaminated water may be purified by the use of cationic and anionic exchange columns (de-mineralisers) and also by distillation. The mere boiling of water contaminated with radioactivity is of no value. The accepted safe tolerance level for water containing fission products is 4×10^{-6} microcuries/cc. Acceptable emergency activities for drinking water are given in Table 2, Section 3.3 of Chapter 3.

A method of removing dissolved fission products from potential drinking water supplies in the field has been developed at the Water Pollution Research Laboratory (DSIR). Reference (1) deals with field trials of a 1/20 scale apparatus that was used at Operation Buffalo. The apparatus worked effectively, with the exception of the removal of radioactive iodine.

Factors affecting the usability of contaminated foodstuffs are discussed in Reference (2), of which further details are given in Chapter 3, Section 3.3.

References

(1) A.W.R.E. Report No. T4/57 (Confidential) - "The Decontamination of radioactively contaminated drinking water in the field".

(2) A.W.R.E. Report No. O-34/56 (Official use only) - "Ingestion of Food Contaminated by Atomic Explosions".

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8.6. Protective Measures

The best protection against radioactive contamination is to use surfaces which are resistant to such contamination or from which the activity may be easily removed. Large-scale measures of this kind would hardly be feasible, but some action could be taken where there is a high probability of contamination, and anti-contamination measures are desirable.

Certain materials, such as polythene, P.V.C. and paper of suitable strength, may be used for form thin protective surface layers on various articles.

Structural materials such as brick, concrete, and wood are a special problem, since the complete decontamination of porous materials is almost impossible. The best means of protection is a good coating of a sealing agent such as paint. In designing structures, the avoidance of cracks, concavities, inaccessible spaces and poor drainage, would facilitate decontamination operations.

A means of protection which could be used where large quantities of water are available is the pre-wetting of exposed surfaces. For example, by saturating the paintwork on a ship with water, the uptake of reactive contamination from mist or spray is greatly reduced, and the surface may easily be decontaminated by further washing with water.

Barrier paints are particularly suitable for the protection of aircraft surfaces. The requirements for a barrier paint or film include ease of application, ease of removal, durability and weather resistance. The satisfactory use of barrier paints at British Trials is reported in Reference (1).

A further point is that where vehicles and the like are to enter an active area all non-essential accessories should be removed to minimise the work of decontamination. Canvas canopies on trucks are an example.

References

(1) A.W.R.E. Report No. T22/57, Operation Buffalo, Decontamination Group Report, Parts 1-4. (Confidential)

8.7. Waste Disposal

The disposal of contaminated waste is a problem which must be overcome in any decontamination work. The exact method used in any particular case will be determined largely by the circumstances, but ultimately disposal can be achieved only by dilution or storage.

The disadvantage of hosing down (except at sea) is that large volumes of water must be diposed of.

All highly contaminated waste, whether in solid or liquid form, must be collected and stored, or buried at sea or on land. In some cases it is possible to reduce the volume and concentrate the waste by burning, but care must be taken not to release the radioactive dust into the air.

Contaminated water of low activity may be allowed to soak away through the soil, which will absorb much of the activity. In an emergency, the disposal of contaminated water into the sewage system might be permissible.

In the case of burial of solid material (or soak-away of water) the site must be marked so that subsequent accidental exposure to the residual activity may be avoided.

8.8. Recommended Decontamination Agents - Composition and General Application

The agents listed in this section are based on an A.W.R.E. Report (Reference (1)), but have been amended to include some more recent formulations recommended by the author of that report.

A. Detergent

"Fully-built" synthetic detergents are far more effective than the simple "unbuilt" detergents, although the latter are better than nothing.

A suitable formulation for the fully-built type is as follows:-

Alkyl aryl sulphonate (Nervan EL.)	2.5 parts
Sodium Tripolyphosphate	8 parts
EDTA Acid	0.25 parts
Cellofas	0.25 parts
Soda Ash	1 part

This may be used at 0.3% w/w upwards. (5 oz./10 galls. upwards).

Uses - All general work, especially on smooth surfaces.

Hazards - None, c.f. normal domestic detergent.

B. Strong Alkali with Detergent

Any strong alkali may be used; caustic soda is very strong and cheap and is thus very suitable. Use 3 to 16 ozs. per gallon of solution as the severity of treatment demands. 1½ ozs. per 10 gallons addition of a wetting agent or detergent (Lissapol N is suitable) will aid the penetration of this solution.

Uses - Paint stripping etc., quickest when hot. Use at full strength. Degreasing - more dilute solutions may be used, or caustic soda replaced by sodium metasilicate or trisodium phosphate. More efficient when hot. May be used in conjunction with a scouring powder such as pumice. May not be used on aluminium and magnesium alloys.

Containers - Steel buckets, cans and tanks are suitable.

Hazards - Corrosive; must be kept away from skin, tongs and/or rubber gloves should be used.

C. Complexing Detergent Solution

An example of this is SDG3, which comprises:-

EDTA Acid	1 part
Citric Acid	2 parts
Sodium Carbonate	0.6 parts
Water	1 part
Alkyl Sulphate Detergent (20%) solv.	1.5 parts
Sodium Sulphate (anhydrous)	2.5 parts

The normal working strength is 0.8% w/w. The pH valus should be 3-4. A considerable improvement will result from the addition of one part sodium fluoride, but the mexture will then be poisonous.

Far more effective if used hot or with steam.

Uses - The above preparation is more effective if used as a bath treatment or applied as a cream after thickening with 2% w/w sodium alginate (Manutex SA/KP) and left for a short time to act, rather than if used as a straight wash down as a detergent. The solution is suited to all surfaces, especially paint, plastics, non-ferrous metals, glass and textiles.

Containers - Enamel buckets and cans are very suitable, but where these are not available steel or galvanized buckets or tanks may be used, in which case it is preferable that they be given one or two good coats of paint, preferably bitumen paint, on the inside. Stainless steel is the ideal material, brass is a reasonable second best.

D. Laundry Detergent

The solution given under Type A above will prove adequate for the treatment of clothing in commercial laundry machines. Where soft water is available a soap-based detergent liquor is to be preferred, for example:-

	Nominal Washing Strength
EDTA Acid	0.02% w/w
Soda Ash	0.09%
Sodium Tripolyphosphate	0.2%
Cellofas B or D	0.01%
High Titre Soap	0.1%

In severe cases the EDTA and Soda Ash content may be raised to 0.05% and 0.12% respectively. The pH value should be 9.5.

The process may follow the standard pattern, but without any initial breakdown soak. In a two-wash process the first wash may be at 140 - 160°F, the second up to boiling if the goods will allow. The exact quantity of stock solution will vary according to conditions.

Severe contamination of clothing may be removed by an overnight soak in the Complexing Detergent Solution, after the above process.

E. Detergent

This is a special detergent for grease and possesses very good emulsifying powers. The only British detergent of this type is Lissapol N (I.C.I.), (Stergene), and may be used at strengths between 4 and 80 oz. per 10 gallons. In cases where a reactive contamination is present, a complexing agent (Sequestrol M, 8 oz. per 10 gallons) may be added with benefit.

Uses - Degreasing and cleaning of surfaces generally, but particularly where strong alkali, etc., is undesirable.

Hazard - None. Prolonged contact with skin should be avoided.

Note - This detergent is normally cloudy in hot solutions. It rinses off better in cold water.

F. Scouring Powder

Fine pumic powder or any proprietary scourer may be used here. A more satisfactory preparation is made if a detergent and complexing agent are also added. The following is a very satisfactory preparation and is non-drying:-

Scouring paste:	8% SDG3 (vide C)	30 parts dry weight
	300 mesh Pumice Powder	40 parts
	Glycerine	20 parts
	Sodium Alginate (Manutex SA/KP)	1 part

Uses - General cleaning of all non-porous surfaces, especially hard materials. Very useful decontaminant where non-abrasive methods fail.

Hazards - None. Many other abrasive powders, e.g. titanium oxide, felspar, etc., may be used in place of pumice.

G. Acids

A wide range of acids may be used where such are permissible. For ferrous materials standard rust removing acids are satisfactory, e.g. sulphuric acid, at 1-25% strength.

Other good mextures are:-

a - oxalic acid (1% upwards)

b - 6% nitric acid plus 1% sodium fluoride

c - 2% oxalic acid plus 1% sodium fluoride.

Uses - These may be used on almost any surface where fast or highly efficient decontamination is required. Metals will tend to dissolve, and glass will be etched to some extent by the fluoride solutions.

References

(1) A.W.R.E. Report No. O-49/55 - "A Guide to Radiological Decontamination after a Nuclear Explosion or Radiological Attack". (Official Use Only)

8.9. Recommended decontamination techniques for specific cases.

Surface or Article	Decontaminating Agent	Ref. Sect. 8.8	Type of Contamination and Action	Procedure	Remarks
Asphalt, Bitumen	Water from hoses, with brushing		Very effective for inert dust, less effective for reactive contamination; erosion.	Work from less active to more active areas, and downhill on sloping surfaces. Brushing may be used with advantage.	Activity will collect in gullies and drain traps. Suitable for large areas. Avoid undue spray.
	Scrubbing with detergent	A	All types of contamination.	As above.	Suitable for smaller areas.
	Strong alkali with detergent	B	Ditto Dissolves surface.	Work in small patches Sluice down with water after treatment.	Suitable for smaller areas.
	Complexing detergent solution.	C	Effective for reactive contamination. Dissolves contamination.	Work in small patches, apply solution, keep wetted with spray if necessary, leave for 30 minutes or longer and finally wash off. Use as hot a solution as possible.	Applicable to small special areas. Solution is relatively expensive.
Brick Concrete	Vacuum cleaning (preferably with brush)		Suitable for dry dust contamination on rough surfaces.	Usual technique, work downwards.	Special machines are preferred. Machine becomes contaminated. Means of safe disposal of effluent air are required (special filters). (Respirators may otherwise be required).
	Hosing down and brushing		Suitable for inert dust, and on relatively smooth surfaces.	As for Asphalt	Wetting is likely to fix reactive contamination in the surface layers.
	Flame cleaning		All types of contamination. Spalling of surface.	Hot oxyacetylene flame used.	Useful in some cases. May be used prior to grinding or blasting.
	Surface grinding or blasting		All types of fixed contamination. Abrasion and removal of surface.	Any of the usual techniques may be used. Work downwards.	It may be preferable to wet the surfaces first. Operator will require respirator.
Clothing	Vaccum cleaning		Useful for dry dust contamination.	Use small nozzle.	Sometimes useful prior to laundering. (See remarks under Brick and Concrete)
	Normal laundering (preferably soap, sodium pyrophosphate and carboxymethyl cellulose, otherwise usual detergents)		Best method for inert contamination.	Normal laundering methods. Soap and soft water far superior. Avoid excessively alkaline conditions. First wash at pH 10, following washes initially pH 8, rising to 10.	Means for effluent disposal required.
	Special procedures. Soap wash, followed by a soak in complexing detergent solution.	D	Best method of reactive contamination.	Usual laundering methods but with addition of a soaking stage. (Stir occasionally during soaking). Alternatively boil with complexing solution 15 minutes (see text)	Special chemicals required, but other methods will have little effect. Wool is more difficult to decontaminate than cotton and other fabrics.

Surface or Article	Decontaminating Agent	Ref. Sect. 8.8	Type of Contamination and Action	Procedure	Remarks
Waterproof Clothing (Rubberised and Oilskins)	Detergent	A	Inert dust and reactive contamination	Wash down and scrub any high spots, rinse down with water (Only cold or warm water is admissible)	Seams are liable to retain activity.
	Complexing detergent solution	C	Reactive contamination	As above. A long soak may be used if necessary. Preferable to use warm solution.	
	Fine pumice or other scouring powder	G	All types of contamination	Scrub with reagent and rinse well. Repeat if necessary.	Most effective treatment.
Canvas Rope, etc.	Vacuum cleaning		Dry dust contamination.	Use fairly small smooth nozzle.	Useful first step. See remarks under Brick and Concrete)
	Detergent	E	Inert dust and reactive contamination.	Scrub down, hot water if available, rinse off well.	Canvas and rope work are difficult to clean.
	Complexing detergent solution	C	Reactive contamination.	Soak with occasional agitation for as long as permissible, and as hot as permissible.	
Glass	Detergent	A	All types	A normal wash down or scrub if necessary. Work downwards.	Inspect any frame or mounting for holes prior to washing. If leaky frames are found, wash with damp cloth rather than with excess water.
	Complexing detergent	C	Reactive contamination.	As above. Use warm solution.	As above. This treatment should be necessary only in severe cases, or possibly in less severe cases where the glass is frosted.
Greasy Surfaces (In all cases where grease is present, most of the contamination will be removed with the grease)	Emulsifying Solvent Cleaners e.g. 1 part Lissapol NX 1 part Lubrol MOA, 9 parts Kerosene		All types of contamination adhering to grease and oil films.	Work cleaner into grease deposit to dissolve. Hose off cleaner and dirt with high pressure hose.	Economical and Effective. Preferred Method.
	Organic Solvents. (Trichlorethylene, white spirit, Petrol, Kerosene, Cresol, etc.		All types of contamination (reactive contamination will be relatively unreactive in these solvents and the danger of fixation of contamination will be less)	Usual techniques. Washing down, using swabs dipped in solvent. Bathing in solvent. Solvent spray, etc. In each case wiping of the surface is desirable. Vapour degreasing will not be as effective.	Usual precautions necessary in the use of these solvents must be observed. Means for disposal or recovery of these solvents will be required. In the case of clothing normal dry-cleaning will be of little use.
	Steam (with detergents if available)		Inert contamination mainly.	Work downwards from the windward side of work.	
	Hot detergent	E	Mainly inert contamination or reactive contamination if complexing agent is added.	Hot bath, spray, or hose depending on object and size.	Useful for light aluminium and magnesium alloys.
	Strong alkali with a little detergent	B	As above	Hot or boiling, bath or hose.	Not suitable for above metals. Avoid splashing and spray. Means of disposal required. Dilute if necessary.

Surface or Article	Decontaminating Agent	Ref. Sect. 8.8	Type of Contamination and Action	Procedure	Remarks
Hard grease and grime	Fine pumice or other scouring powder	F	All types of contamination. Abrasive	Rub on in paste or powder form, scrub if necessary. Wash off well. Work in small patches, one at a time.	Very effective where other methods fail. Suitable for small objects not of a precision nature.
Hair	Detergent	A	All types of contamination. Less effective for reactive contamination	Shampoo hair in warm water in normal way, repeat if necessary, rinse well	Any usual soapless shampoo is satisfactory.
	Complexing detergent solution	C	For reactive contamination left after above treatment	As above. Rinse well	Hair is difficult to decontaminate from reactive contamination. Usually safest to trim off hot locks.
Human Skin	Soap (Mild toilet) (Wood, flour or fullers earth may be added)		All types of contamination, especially inert	Wash well in soap and warm water scrubbing with a soft brush. Repeat until clean	Preferred procedure in all cases.
	10% Potassium permanganate, 2% Sodium bisulphite		All resistant contamination	Rub or swab on the permanganate solution for a minute or two, wash off, and decolourise with bisulphite applied similarly	Usually used only when the above fails. In the case of any cuts, wounds, sores, etc., medical attention should be sought.
Metals (see also Surfaces)	Hosing and brushing with water		Mainly inert contamination	See remarks for "Asphalt"	Useful for large areas
	Detergent	A	As above	See remarks for "Asphalt"	
	Organic Solvents and Emulsifying Solvent Cleaners		All types of contamination	See remarks for "Greasy Surfaces"	
	Complexing detergent solution	C	Reactive contamination	Wash down in normal manner	Suited to light metals which would be attacked by more severe treatments. (e.g. aluminium alloys)
	Fine pumice or other scouring powder	F	All types of contamination	See Remarks under "Hard Grease and Grime".	Suitable for all metals but not on precision parts
	Metal polish		All types of contamination	Usual method of application, change rags frequently	Suitable for small and delicate parts
Heavy metals iron and steel etc.	Industrial de-rusting agents, especially inhibited phosphoric and other acids	G	All types of contamination	Soak in bath with occasional brushing, hose down, or wash down with the solution. Rinse well afterwards, dry, and grease to prevent rusting.	Fast and complete decontamination. Acid should be handled with care and splashing avoided
	Sand blasting (preferably wet)		All types of contamination	For dry sand blasting a special box is preferable. Wet sand blasting less hazardous	Complete surface removal with accompanying damage. Contamination may be spread over large area. Suitable only for large rough objects.

Surface or Article	Decontaminating Agent	Ref. Sect. 8.8	Types of Contamination and Action	Procedure	Remarks
Paint	Hose and brush down with water		See remarks under "Asphalt"		First step in dealing with large areas, particularly in cases of inert dust contamination
	Detergent	A or E	As above		Run off water should be controlled, and not allowed to flow towards clean areas
	Complexing detergent solution	C	Reactive contamination	See remarks under "Asphalt". Use hot solution (Preferably PH5)	In case of buildings care should be taken to see that contaminated water does not flow into or be driven into an uncontaminated interior.
	Fine pumice powder or other scouring powder	F	All types of contamination	See remarks under "Hard Grease and Grime"	
	Trisodium phosphate		All types of contamination	Rub surface for a few minutes with rag moistened with hot 10% solution, wipe dry, use clean rag for subsequent application	Surface removed. As above
Stripping Agents	Steam (with detergent (if available)		See remarks under "Asphalt"		
	Strong alkali preferably with a little detergent	B	All types of resistant contamination	Soak surface or paint on, leaving for 1 to 2 hours, hot or cold, wash off, and scrape off any remaining paint	Complete stripping of paint. Not suitable for aluminium or magnesium alloys. Splashes should be avoided.
	Organic solvents, e.g. trichlorethylene, and industrial paint stripping compounds		All types of contamination	Immerse, wash and scrape or use usual methods of application in the case of industrial strippers	Should be used in a well ventilated space and usual precautions for solvents taken.
	Burning off		All types of contamination	Usual technique, burn and scrape	Useful for exterior paintwork window panes, etc., only. Hazardous.
	Sand blasting		See under "Heavy Metals etc."		Suited to hard finishes, e.g. vitreous enamels.
Plastics	Detergent	A	See remark under "Glass"		
	Complexing detergent solution	C			
	Fine pumice powder or other scourer	F	See remarks under "Hard Grease and Grime"		
	Metal Polish		All types of contamination	Use in normal manner, replace rag at frequent intervals	Useful on hard smooth plastics, e.g. perspex and bakelite

Surface or Article	Decontaminating Agent	Ref. Sect. 8.8	Type of Contamination and Action	Procedure	Remarks
Leather	Water		Inert dust contamination.	Polished leather may be cleaned, by wiping with a damp cloth.	
	Brushing		As above.	A good brushing in the welts will help to remove dust from boots.	
	Organic Solvent		All types of contamination.	Wipe polished leather with a cloth dipped in a solvent will remove activity with the polish and oils.	Leather so treated should be repolished immediately.
	Wire Brush or Sanding		All types of contamination when dry.	A good stiff brushing with a wire brush will be effective in removing the surface layer.	Avoid dust. Suitable for soles and heels. Failing this, leather should be discarded.
Rubber	Detergent	A	Inert contamination mainly.	Good wash down, and scrub, preferably hot.	First step in decontamination of rubber.
	Detergent	E	Inert contamination held by grease.	As above.	This is preferable to the use of organic solvents.
	Organic Solvents, especially acetone. (not recommended for general use)		All types of contamination.	Swab over quickly, do not allow the solvent to remain in contact for long.	Not recommended for general use, suitable for greasy patches only.
	Complexing detergent solution.	C	Reactive contamination.	Soak goods in hot solution, or wash down. Length soaking is more efficient. Rinse well. (Rubber may be boiled in this solution with benefit)	Applicable to all types of rubber.
	Acids, industrial de-rusting agents, e.g. inhibited phosphoric acid.	G	All types of contamination, especially reactive.	Soak goods in solution for as long as permissible, or in case of large objects wash down. Brush. Rinse well.	Most rubbers are resistant to these compounds. Care will be required in their use, splashes should be avoided.
	Fine pumice or other scouring powder	F	All types of contamination.	Rub on in usual manner, wash off well.	Surface abrasion. More suited to hard rubbers.
Soil	Land scrapers and bulldozers		All types of contamination.	Soil should be damp but not wet.	Only method available. Means for burial or other disposal of large quantities are required.
Tile and Slate	Vacuum cleaning		Suitable for dry dust contamination.	See remarks under "Brick and Concrete"	Useful for porous and rough surfaces.
	Hose down and brush		Mainly inert contamination.	Work downwards, directing hose down slope. Brushing down will be an advantage.	Care should be taken to avoid the entry of water into uncontaminated building interiors.
	Trisodium phosphate or other strong alkali	B	All types of contamination.	Scrub hot 10% solution onto surface flush down with water.	Surface removal. Good for floor tiling.
	Surface grinding or blasting.		See remarks under "Brick and Concrete"		

Surface or Article	Decontaminating Agent	Ref. Sect. 8.8	Type of Contamination and Action	Procedure	Remarks
Wood (Unpainted	Vacuum cleaning		Mainly inert contamination	(See remarks under "Brick and Concrete"	Useful for flooring, especially rough surfaces.
	Scrubbing with Detergent	A	Mainly inert contamination.	Work downwards, avoid entry of water into uncontaminated areas and spaces.	Suitable for upright woodwork, weather-boarding, etc.
	Planing, scraping, sanding.		Suitable for all types of contamination. (Surface removal)	Conventional techniques. Preferable to wash down as above, and allow to dry prior to present treatment.	Suitable for floors, table-tops, etc. but laborious. (Dust hazard)

All the Tables in this Section are reproduced from A.W.R.E. Report No. O-49/55 "A Guide to Radiological Decontamination after a Nuclear Explosion or Radiological Attack" (Official Use Only)

CHAPTER 9 - RADIAC INSTRUMENTATION

The term "RADIAC" is a contraction of the phrase "Radiation Detection Identification And Computation" and is an international and inter-Service term applied to instruments designed for use by personnel involved in atomic warfare, for various monitoring processes which are discussed below.

9.1. Types of Radiation.

The types of radiation emanating from a nuclear explosion have been discussed in Chapters 1-3 of this Part of the Manual, and definitions are given in Part II (Glossary).

There are four main types of nuclear radiations resulting from an explosion, namely:-

(a) Gamma-rays
(b) Beta particles
(c) Alpha particles
(d) Neutrons.

Of these radiations, alpha particles constitute a hazard which is likely to be met only in special circumstances, e.g. the disposal of unfissioned material, and hence the measurement of alpha particles is not included as one of the standard requirements for a Radiac instrument.

Beta radiation constitutes a definite part of the residual radiation from an atomic explosion, i.e. from the fallout. Considerations for and against including beta measuring facilities in Radiac instruments are discussed in Section 9.3.

Gamma radiation resulting from an atomic explosion may be considered in two categories. Firstly, that from the actual explosion itself ('prompt', 'initial', or 'immediate' gamma radiation), and secondly, that from the fission products which fall out ('residual' radiation). Radiac instruments are designed to measure gamma radiation.

Surplus neutrons from the fission process can escape from the actual explosion, and in the case of a comparatively low burst, can reach the ground.

In most practical situations the other bomb effects are more likely to be lethal than the neutrons, and so no provision is at present made for neutron measurement in Radiac instrumentation.

In the Armed Services and Civil Defence Service*, instruments are therefore required for the following purposes:-

(a) Measurement of doses of gamma radiation received by personnel.
(b) Measurement of dose-rates from the radioactive contamination of ground, etc.
(c) Measurement of dose-rates from the radioactive contamination on the clothing and bodies of personnel, and on vehicles, etc.
(d) Measurement of the degree of contamination on food and in drinking water.
(e) Measurement of radioactivity for specialised purposes.
(f) Training.

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* Subsequently in this chapter, "Service" will imply the Armed Services and Civil Defence.

9.2. Measurement of Personal Doses (Flash Dosimeters)

There are two types of radiation dose which are important to the individual - initial radiation received from the actual explosion, and residual radiation, received from the radioactive cloud or from fallout deposited on the ground.

It has been stated (reference Chapter 2) that a single dose of 450 roentgens will cause the incapacitation within 24 hours of all who receive it, and ultimately the death of about 50% of the recipients. An instrument is therefore required that will measure doses of gamma radiation of up to (say) 500r when emitted at a very high dose-rate. Such instruments have been termed "Flash Dosimeters" and may be of several types, described in Table 1. While all the following principles are theoretically sound, work in the U.S., Canada and this country has shown that several methods are unsuitable for Service use. Comments on this are given in the last column of the table.

Of the types listed in Table 1, only 'd' and 'e' - the Phosphate Glass and Quartz Fibre Dosimeters - are in British Service use.

The dose-rate at which doses from residual radiation are received is very much lower, and any instrument designed to work under high dose-rates will operate in these lower conditions. However, the dose to be measured is also appreciably lower. The flash dosimeter is intended basically for use by Service or emergency medical organisations to enable assessment of the correct treatment, and by the Commander in the field to assess the fighting potential of his troops. A dosimeter intended for measuring residual radiation (or radiation from a radioactive source or reactor) is intended to give a measure of the radiation received by an individual, and so ensure that he does not receive more than the tolerable dose for the particular circumstances. Thus a radiation worker in an establishment using a reactor or in a store holding radioactive sources would be restricted to 0.1r per week, while troops in the field or Civil Defence personnel in an emergency might have to be subjected to a single dose of 25r or even higher.

For reasons of sensitivity only photographic, phosphate glass and quartz fibre types of flash dosimeter are suitable for measuring doses of less than 50r. The photographic dosimeter is unsuitable in the field, as already stated, for technical reasons.

The Phosphate Glass dosimeter is suitable for Service use where incremental doses of (say) 10r or more, are of importance.

The Quartz Fibre dosimeter (designed so that the instrument is of the correct range) will cover any maximum dose from 0.5r to 500r, or even higher. Selection of a suitable range is therefore possible. Thus workers in Ordnance Depots holding radioactive sources use the 0 - 0.5r instrument; troops in the field would carry the 0 - 50r or 0 - 150r instruments as well as the 0 - 500r.

The term "Flash Dosimeter" has been used here to describe a dosimeter suitable for use in measuring initial radiation, i.e. that received at a very high dose-rate. The official Service terms "tactical", "residual" and "technical" are used to denote dosimeters of varying ranges and uses. Broadly speaking the tactical dosimeter is intended for measuring the large doses of radiation received at high dose-rates from the actual

nuclear explosion and enables a quick assessment of the fighting potential of the troops to be made. The residual dosimeter is used to measure the gamma dose received by its wearer when operating in a radioactively contaminated area. The technical dosimeter is used to measure the dose received from low activity radioactive sources and, as such is worn by personnel handling training sources etc.

TABLE 1 - Types of Flash Dosimeter

Type	Principle	Comments
a. Photo-graphic	Ordinary film, (in this case "dental film" used for X-ray photo-graphs of teeth) is blackened on exposure to gamma radiation. The density of the blackening can be measured and converted to a measurement of dose.	This method is used in Atomic Energy Establishments etc. where processing may be done under controlled conditions. "Service" types incorporating a developer are not particu-larly suitable and have tended to be rejected in favour of better principles. Low cost.
b. Chemical	Gamma radiation will cause the formation of HCl from a mixture of a chlorinated paraffin (e.g. carbon tetrachloride) and water. The amount of HCl formed, expressed as a pH value is related to the dose and may be measured by the colour change of suitable indicators.	Used in the U.S. - Individual Dosimeter E1R3, consisting of five tubes designed to change colour at 50, 125, 175, 300 and 450r respectively. Dosimeter reacts to sunlight and is generally not very reliable. Fairly low cost.
c. Crystal	Crystals of alkali halide (e.g. potassium chloride) become coloured on exposure to gamma radiation. Colour may be matched against samples mounted contiguous to the crystal or on some colori-meter.	Colour matching by eye is difficult as it is only the depth of colour that is affected by additional doses. Provision of a colorimeter would increase the cost. Crystal bleaches in strong light which is a disadvantage although it means that the crystal can be intentionally bleached and re-used.
d. Phosphate Glass	A phosphate glass activated with a small quantity of silver, will fluoresce under U.V. light after irradiation by gamma-rays. The fluorescence is measured and com-pared against a standard, the ratio being converted to give a meter-reading in roentgens. The reader can be operated from the mains or other equivalent supplies powered by wet batteries. Opera-tion from dry batteries would require a special design of reader with low current consumption.	Dosimeters cost about 5s.0d. but reader costs about £150. A satisfactory type of dosi-meter where incremental doses of less than about 10r do not have to be measured, i.e. on operations.

Type	Principle	Comments
e. Quartz Fibre Dosi-meters	Consists of an ionisation chamber to detect the radiation, with a gilded quartz fibre electrometer which is read through an optical system built into the dosimeter. The instrument which is normally the size of a large fountain pen is charged up to read "zero". Gamma radiation causes the dissipation of a proportion of the charge, the amount being read on the electrometer as a reading in roentgens. Chargers may consist of a source of H.T. from batteries (i.e. a 150 volt battery or a L.T. battery and vibrator or transistor unit) or an electromagnetic unit incorporating a hand generator. The last type is used in British chargers. Some means of transferring the charge from the charger to the dosimeter and of adjusting the charged dosimeter to read zero must be incorporated.	Cost about £5 each. Very robust. Owing to difficulties in collecting all the ions formed in the ionisation chamber when the instrument is exposed to higher dose rates, these dosimeters tend to underread when measuring full-scale doses of 'prompt' radiation, if their scales have been calibrated on doses applied more slowly. The correction factor on an existing design of 500r dosimeter (the QF No.5) is about x1.4, but it is feasible to design 500r dosimeters with substantially complete collection under flash radiation conditions.

9.3. Measurement of Contamination of Areas (Survey Meters)

Instruments designed for reconnoitring and surveying contaminated areas are now known as "Survey Meters". This is an inter-Service and standardised NATO term which replaced the old U.K. term "Portable Dose-Rate Meter".

In view of the fact that a dose of 25 roentgens can be accepted as a military tolerance in operational conditions, and also the fact that the activity of the fallout of an atomic weapon decays according to the $T^{-1.2}$ law, the ranges required on the Service survey meter are probably 0.05r/hr to 300r/hr, but the majority of readings will not exceed 3r/hr.

Measurement of dose-rates such as these can be easily carried out with a simple ionisation chamber/electrometer valve circuit, in which the ionisation current is used to develop a voltage across a high value resistor in the grid circuit of a specially designed triode called an electrometer valve. Any change of this voltage is measured by a microammeter in the anode circuit. The usual principle is to use three different grid resistors varying by 10:1 ratios and hence have three ranges on the instrument, e.g. 0 to 3, 0 to 30, and 0 to 300 r/hr.

As an alternative to this, the pseudo-logarithmic characteristic which results from a free grid circuit may be used. In this circuit the ionisation chamber current is balanced against the grid current, the change in anode current being measured by a meter. In this type of meter the three decades 0.5 r/hr to 500 r/hr may be read without switching.

In their basic design, survey meters are sensitive to gamma radiation only, as the ionisation chamber is usually enclosed in a metal or plastic case. If however, the ionisation chamber has one side closed with a thin window (of surface density not exceeding about 40 mg/cm^2), then any beta particles incident on this window with energy exceeding a certain threshold will penetrate the window and cause ionisation in the chamber. It is therefore possible for the instrument to indicate the presence of beta radiation. If some form of shutter is fitted to the beta window, it is possible in a given field to obtain a measurement of the gamma dose-rate when the shutter is closed and an indication of the beta + gamma dose-rate when the shutter is open. (The beta hazard is of some importance with fission product activity.) The ratio of beta dose-rate to gamma dose-rate will depend on the terrain over which the measurement is taking place since the beta radiation is of less effective range than the gamma. Hence, in the two circumstances shown in Figure 1, in (a), the man is receiving gamma radiation from a distance as well as from his immediate vicinity, while the beta radiation is received effectively from his immediate neighbourhood only. In (b), the gamma dose-rate is appreciably reduced by the surrounding buildings while the beta dose-rate is the same. Thus an instrument which measures gamma radiation only will give a lower reading in case (b), while in fact the beta dose-rate is the same. If therefore an estimate of the latter is based on a particular beta/gamma ratio, an erroneous conclusion will be formed in one case.

In addition, the beta/gamma ratio depends also on the beta energy spectra of the fission products, which vary with time. Typical figures for beta/gamma ratios for plane surfaces are 15:1 a few hours after burst, dropping to 4:1 after three weeks, and then rising slightly after three months.

The beta dose associated with a gamma dose of 25r is estimated to be about 300 rep, and hence the beta hazard will not normally be in excess of that estimated from the gamma hazard. However, these ratios apply to measurements at about three feet from the ground. In cases where the fission products are in contact with or close to the skin, e.g. when a man is lying down, the figures are much higher - figures of over 100:1 have been mentioned. In these cases, the beta hazard may exceed the gamma hazard, but may still be estimated from the gamma measurement if certain basic assumptions are made.

A certain degree of interference from radar is experienced by ionisation chamber instruments that are not screened, i.e. have non-metallic cases. The interference occurs mainly in the centimetric and millimetric bands (10,000 Mc/sec - 3,000 Mc/sec) and may manifest itself as either a negative or a positive reading. The trouble occurs only when the instrument is in the direct beam of the radar set and then only when within (say) 200 yards of it. It can be prevented by encasing the instrument in a metallised bag or in a thin metal carrying case.

reading. Trials at Operation Buffalo indicated that an ionisation chamber instrument of design similar to the Survey Meter No. 2, with a beta-sensitive ionisation chamber, was capable of being used as a 'frisker' in quite high backgrounds. As an example, a degree of contamination which would give slightly under a full-scale reading on the Contamination Meter No. 1 used as in method (a) above, gave a reading of 1.5 r/hr. on the Survey Meter No. 2 used as a 'frisker' with its beta window open. The background was 100 mr/hr - ten times full-scale on an unshielded Contamination Meter No. 1 but only 1/30 full scale on the bottom scale (0 to 3 r/hr) of the Survey Meter No. 2.

The advantage of using a beta-sensitive instrument is two-fold; firstly, the range of the beta particles is sufficiently small that the instrument can delineate the boundaries of the contamination more accurately, and secondly, the ionising capabilities of beta particles are greater than for a similar number of gamma photons, hence an enhanced reading is obtained. The scales of instruments calibrated for gamma radiation only indicate the degree of beta radiation, and do not measure in any particular units.

As a result of this, future policy, at least for the Army, will be in terms of a combined Survey/Personal Contamination Meter as it will be technically possible to combine the two instruments. This is also very convenient tactically.

A sensitive instrument is required for monitoring food and water, as the degrees of contamination liable to prove hazardous on ingestion are relatively low.

The Contamination Meter No. 1 is suitable for this purpose, and is used as a 'frisker' for measuring the contamination on food.

To measure the contamination in water, the probe may be held at a fixed distance from the water, or alternatively, a special beta-sensitive G-M tube into which a sample of the water may be poured, can be used.

Special devices have been developed to measure long-lived alpha activity in personnel, food, air and water.

9.7 Details of Current Radiac Instruments

The specifications for current Radiac instruments include such requirements as:-

Climatic, Rough Usage and other Inter-Service tests
Portability
Response to radiation of different energies
Response to different dose rates
Accuracy of recording.

Generally, the "technical" requirements such as response and accuracy are a compromise between those which can be obtained in a laboratory instrument and the need for Service conditions to be met.

Detailed specifications for each instrument are available (see bibliography below) but Table 1 gives information regarding ranges etc. It can be assumed that for use in atomic warfare, that part of the radiation (as regards energy, etc.) which is of significance to man, is always recorded.

In Table 1 details of current instruments are given together with their Inter-Service numbers, their A.E.R.E. numbers, the Services who use them, and any remarks. The list includes all major Radiac instruments but does not record every small part even though it may have a separate Inter-Service catalogue number.

The development of Radiac instruments for all Services is the responsibility of D.L.R.D., Ministry of Supply. The design authority for all these equipments is the Atomic Energy Research Establishment, Harwell.

No transistors are used in any current designs of Radiac instruments. One of the chief reasons for this is that the upper limit of temperature specified in the climatic specifications laid down by the Armed Services has, until recently, been too close to the working limits of suitable transistors for safety.

At Operation Buffalo, a team of six Army Officers carried out a series of trials on Radiac instruments and methods, and a reference to the Team's report is given in the Bibliography. Generally speaking, the instruments behaved quite satisfactorily and gave readings which were within specification tolerances.

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All documents mentioned above are unclassified unless otherwise stated.

Item	Name	Joint Services Catalogue No. 6665-99-911-	A.E.R.E. No.of Prototype	Capabilities	Services using instrument	Production Situation (May '57)	Remarks
11	Meter Survey Radiac No.2	-0008	-	Reads 0 to 3, 0 to 30 and 0 to 300 r/hr. Fitted with beta window	Army, R.A.F. C.D.	P	
12	Meter portable dose rate trainer No. 1	-0010	1191B	Reads 0 to 3 x 10^{-4} r/hr	Army, R.A.F. C.D.	S	Superficially resembles Item 10
13	Meter Survey Radiac No. 3	-0123	1324A	Reads 0 to 30, 0 to 300 and 0 to 3000 mr/hr	Army, R.A.F.	P	For use in stores holding R/A sources
14	Meter Survey Radiac No. 4	-0124	1349A	Reads 0 to 15, 0 to 150 and 0 to 1500 mr/hr	-	-	Beta/gamma sensitive. Mainly for trials use.
15	Meter Contamination No. 1	-0012	1092D	Reads 0 to 10 mr/hr with gamma probe and 0 to 10 mr/hr. with special beta sensitive liquid (re-entrant) probe.		S	All contained in one haversack. Powered by H.T. batteries OR L.T. batteries + vibrator OR Mains
16	Monitor Radioactivity No.1	-0258	1257B	Sensitive to α, β and γ radiation. Reads in counts/sec.	Army, R.A.F.	S	Mains operated. Service version of A.E.R.E. 1021. Title is that used in Army; other Services may vary.
17	Source Radioactive A No.1	-0015	1210A	0.5 mC of Radium. Gives 0.5 mr/hr at 1 yd.	All	S	Used for checking instruments
18	Source Radioactive B No.1	-0016	1210A	100μC of Cobalt. Gives 0.16 mr/hr at 1 yd.	All	S	Used for wearing as "contamination"
19	Source Radioactive C No.1	-0017	1210A	1 mC of Cobalt. Gives 1.6 mr/hr at 1 yd.	All	S	Used for demonstration and training

Item	Name	Joint Services Catalogue No. 6665-99-911-	A.E.R.E. No.of Prototype	Capabilities	Services using instrument	Production Situation (May '57)	Remarks
20	Source Radioactive D No.1	-0018	1210A	5 mC of Cobalt. Gives 8 mr/hr at 1 yd.		S	Used for demonstration and training.
21	Source Radioactive E No.1	-0019	1210A	25 mC of Cobalt. Gives 40 mr/hr at 1 yd.	All	S	Used for demonstration and training.
22	Source Radioactive F No.1	-0025	-	25 mC of Cobalt	All	S	Used for calibrating instruments.
23	Source Radioactive G No.1	-0041	-	5 mC of Cobalt	All	S	" " "
24	Slide rule Radiac No. 1	-0027	-	Will calculate future or past dose according to $T^{-1.2}$ law.	R.N.	S	
25	Radiac Calculator No. 1	-0060	-	" " " " "	Army, R.A.F. C.D.	S	
26	Water Contamination Calculator No.1.	-0057	-	Will calculate hazard due to drinking contaminated water, knowing time after burst	Army, R.A.F. C.D.	S	Obsolescent for Army and R.A.F.
27	Meter Survey Avo, No. 1	NYA	1219	Reads up to 500 r/hr. on logarithmic scale		U/D	Alternative 100 r/hr. F.S.D. being developed for C.D.
28	Radiac Fallout Simulator	NYA		Will give magnetic field resembling "fallout" field	-	U/D	Two models giving "fields" up to 1000 yds. and 5 mls. respectively. Requires special "Survey Meter"

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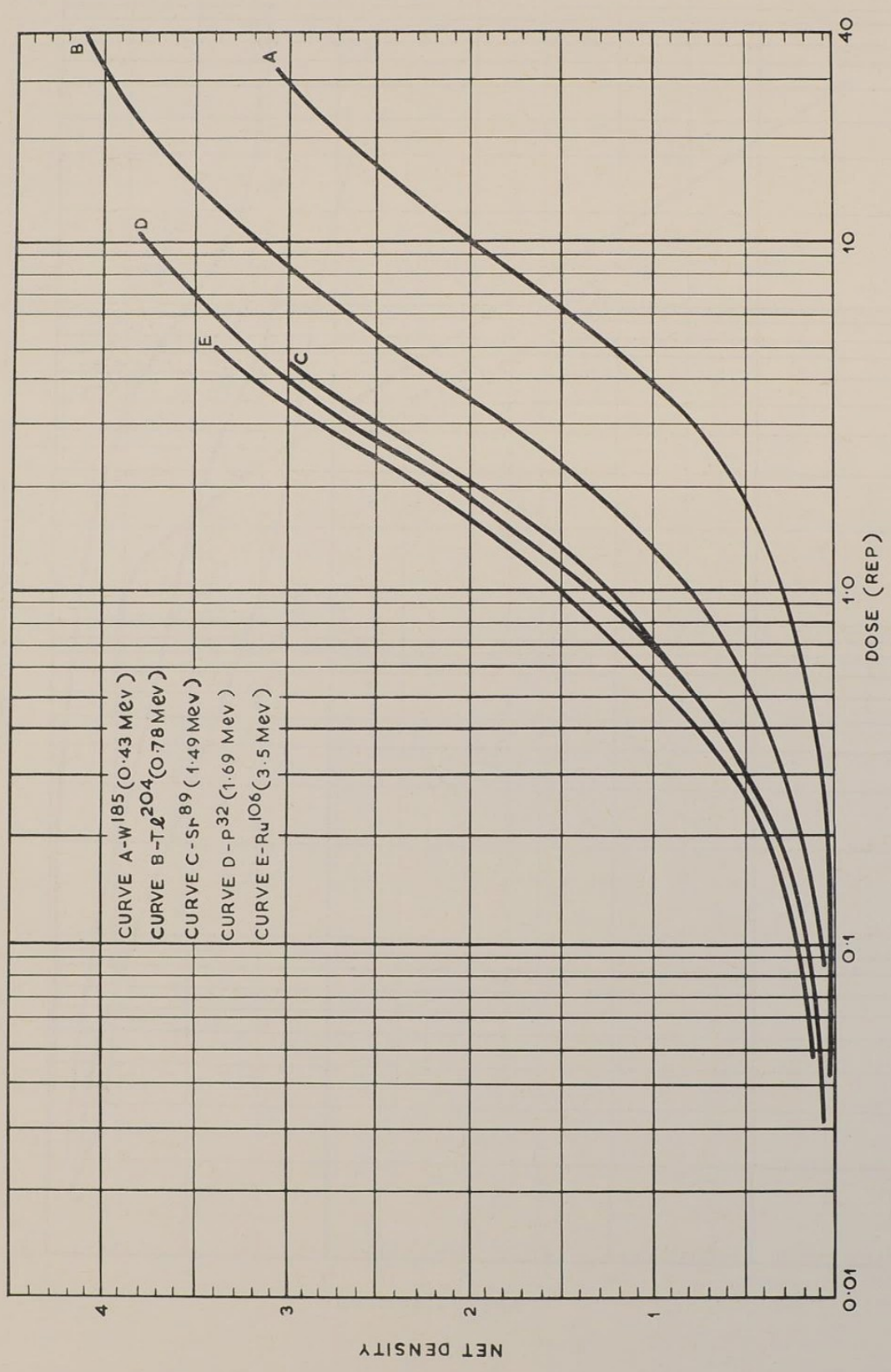

RESPONSE OF PMI FILM (IN ITS WRAPPING)
TO BETA RADIATION

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No.	Originator and Reference	Security Classification	Title
81	C.D.E.E. Porton Tech. Paper (R)15 4th March, 1959.	Restricted	Production of a Simulant for Radioactive Fallout.
82	A.W.R.E. Report T53/57	Secret U.K. Eyes Only	Operation Buffalo. Naval Radiological Measurements. Final Report Part 1. The Polar Distribution of the Flash Gamma Radiation.
83	Nature Vol. 182 (6th Sept. 1958) pp. 629-630	Unclassified	Deposition of Radioactivity in N.W. England from the Accident in Windscale. Chamberlain A.C.& Dunster H.J.
84	Nature Vol. 182 (Nov. 29th, 1958) pp. 1473-1478	Unclassified	Radioactivity Due to Fission Products in Biological Material. W.V. Mayneord. et al.
85	A.W.R.E. Report T59/57	S. Atomic U.K. Eyes Only	Operation Buffalo. Neutron Measurements.
86	A.W.R.E. Report E9/57	Secret/Atomic/ Discreet C.C.	On the Rise of an Atomic Cloud.
87	Home Office Scientific Adviser's Branch Report CD/SA.89 Oct.1958	Restricted	Survey of the Protection Afforded in Private Houses against Radiation from Fallout. D.T. Jones.
88	A.W.R.E. Report T34/58	Confidential	Gamma Dose-Distance Measurements at Operation Antler.
89	A.W.R.E. Report No. T37/58	Secret/Atomic U.K. Eyes Only	Operation Antler. The Shielding from Initial Radiation Afforded by Soil.
90	C.D.E.E. Porton Tech. Paper (R)20 9th April, 1959.	Confidential	Fallout Leaching Studies.

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No.	Originator and Reference	Security Classification	Title
91	War Office Operational Res. Unit - Far East. Report 2/58, November, 1958.	Secret	Attenuation of Gamma Radiation by Tropical Vegetation.
92	A.W.R.E. Report T53/58	Confidential	Operation Grapple-Y. Sampling of Radioactivity at Outlying Stations in the Pacific During April/May, 1958.
93	A.W.R.E. DUPLICATES REF 98 Report E2/58 REPORTS NOW O.U.O	Secret/Atomic Discreet	The Computation of Fallout Pattern, Part 2, Numerical Details. Vol.1. Text. Vol.2. Illustrations.
94	Nature Vol.182 (Sept.6th, 1958) pp. 627-8	Unclassified	Long Range Travel of the Radioactive Cloud From the Accident at Windscale. Steward N.G.L. Crooks R.N.
95	A.W.R.E. Report T44/58	Secret	Operation Antler. Radiological Survey Operation in the Alice Road Area.
96	A.W.R.E. Report O-7/58 January, 1959.	Secret/Atomic U.K. Eyes Only	Bibliography on Radiological Decontamination and on the Nature of Weapon Fallout. Ariss and Stevenson.
97	A.W.R.E. Report T34/58 October, 1958.	Confidential	Operation Antler. Gamma Dose-Distance Measurements.
98	A.W.R.E. Report E2/58. October, 1958	Secret/Atomic Discreet	The Computation of Fallout Patterns Part 2, Numerical Details. Volume 1, Text. Volume 2, Illustrations.
99	C.D.E.E. Porton Tech. Paper (R)11	Secret/ U.K. Eyes Only	Estimation of Ground Contamination and Airborne Concentration in Fallout. D.J. Thomas.
100	A.W.R.E. Report T37/58	Secret/Atomic U.K. Eyes Only	Operation Antler, Target Response Group. The Shielding from Initial Initial Radiation Afforded by Soil.
101	A.W.R.E. Report E1/58 E1/58	Official Use Only	The Computation of Fallout Patterns. Part 1 - General Theory.

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GENERAL REFERENCES: Nuclear Radiation and Fallout from Nuclear Weapons

No.	Originator and Reference	Security Classification	Title
102	A.W.R.E. Report T42/57	Secret/Atomic U.K.Eyes Only	Operation Buffalo. Attenuation and Scattering of Initial Nuclear Radiations.
103	A.W.R.E. Report O-7/58	Secret/Atomic U.K.Eyes Only	Bibliography on Radiological Decontamination and on the Nature of Weapon Fallout. (Details of over 200 References are given, including many brief abstracts)
104	13th Trip. Conf. on Tox. Warfare Paper TCR5/58	Confidential	The Attenuation of Residual Radiation by Structures. Collin and Western.
105	NWS Memo. 159/58 May, 1958	Confidential	Meteorology Aspects of Nuclear Explosions.
106	A.W.R.E. Report T48/57	Confidential	Operation Buffalo. The Penetration of Residual Gamma Radiation into Structures.
107	Res. & Dev. Branch U.K.A.E.A., Risley Report IGRL-IB/R-30 (1957)	Unclassified	Information Bibliography. Radiation Shielding.
108	12th Tri. Conf. on Tox. Warfare Paper TCR10/57	Confidential	Gamma-Ray Spectra of Residual Radiation from an Atomic Weapon. D.H. Peirson.
109	12th Tri. Conf. on Tox. Warfare Paper TCR8/57	Official Use Only	The Effect of Induced Activity in Soil on Dose-Rate from Fallout. G.C. Dale.
110	12th Tri. Conf. on Tox. Warfare Paper TCR3/57	Official Use Only	The Dose Rate Above an Extended Source - Aerial Survey K. Stewart.
111	ARL/N1/R862 June 1957	Confidential	Some Notes and Conclusions on Experiments Arising from the 1952 Montebello Trials with Particular Reference to the Fluid Fallout Hazard. C.A. Luxford.

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GENERAL REFERENCES: Nuclear Radiation and Fallout From Nuclear Weapons

No.	Originator and Reference	Security Classification	Title
112	A.E.R.E. Report HP/M113 November, 1956	Unclassified	Isolation Distances Required for Radioactive Materials in Ships.
113	A.W.R.E. Theoretical Physics Note No. 27/57	Secret/Atomic U.K.Eyes Only	On the Prediction of Fallout Patterns. Beale.
114	Home Office Report CD/SA62 March, 1955	Restricted	The Effective Energy of Fission Product Gamma Radiation. C.B. Lax.
115	ARL/R3/C791 March, 1957	Secret/ Discreet	Operation Mosaic II. The Fallout Analysed with Reference to H.M.S. Diana. E.M.L. Beale.
116	A.W.R.E. Report T24/57	Secret/Atomic U.K.Eyes Only	Operation Mosaic. Theoretical Predictions.
117	A.W.R.E. Report TC1/56	Official Use Only	Estimation of the Energy Distribution of the Initial Gamma Radiation.
118	Home Office Report CD/SA79 August, 1956	Restricted	Developments in the U.K. In Relation to a Fallout Reporting Organisation. McDonald.
119	Home Office Report CD/SA80 November, 1956	Restricted	Condition of the Atmosphere when a C.D. Post is Sealed for Six Hours. McAulay and Collins.
120	Home Office Report CD/SA66 May, 1956	Confidential	A Proposed System of Radiological Control for Civil Defence Operations in an Area Devastated by a Nuclear Explosion. Stanbury

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GENERAL REFERENCES: Nuclear Radiation and Fallout from Nuclear Weapons

No.	Originator and Reference	Security Classification	Title
129	AERE Report HP/R1782 1955	Official Use Only	The Shielding Provided by a Brick House Against the Gamma Radiation from a Uniformly Deposited Source. (Experiments with Cobalt 60).
130	AWRE Report 7/55	Secret	Operation Totem. Radiochemical Analysis - Neutron Flash.
131	HER Report H23/52	Restricted	A Comparison Between Experimental and Two Theoretical Methods for the Solution of Gamma Ray Penetration Problems.
132	HER Report H6/53	Restricted	The Angular Distribution of Multiply Scattered Gamma Radiation from a Point Source.
133	AWRE Report T8/55	Secret	Operation Totem. Fallout Particles from Rounds 1 and 2.
134	AWRE Report TC5/55	Secret	Variation of Dose Rate with Height Above the Fallout Area.
135	A.W.R.E. Report O-62/58	Confidential	The Estimation of the Dose Due to a Radiation Burst From a Transient Super-critical Assembly.
136	Home Office Report CD/SA 94, May, 1959	Restricted	Up-wind Fallout from Megaton Explosions. Stanbury and Western.
137	Air Ministry Science 2. Memo 272 (1957)	Secret	The Effect of Radioactive Fallout on the Operation of Fighter Airfields.

U.K. Reports

DAMAGE TO TARGETS IN GENERAL : Damage by Combined Effects

No.	Originator and Reference	Security Classification	Title
1	Tripartite Conference on C.B. and R.W. 9th Porton (DRB.54/10123)	Secret	Service Aspects, Item 5. Protection against Atomic Attack by Dispersion of Ships and the Use of Smoke to Diffuse Thermal Effects. 21.7.54.
2	War Office, Operation Totem, 1953. Army Equipment Group	Secret	"Interim Summary of Trials Results prepared for D.A.W.R.E."
3	Tenth Tripartite Conference on Toxicological Warfare. A.E.R.E. EL/R.1798, p.46.	Secret	A report on the Meetings on Radiological Defence.
4	1957 Tripartite Conf. ARDE Report (B)46/57	Unclassified	An Approximate Solution of the One-dimensional Transport Equation.
5	Army Operational Research Group, A.O.R.G. Report No. 2/57. March, 1959.	Secret/Discreet/ U.K.Eyes Only	Optimum Burst Heights in the Tactical Use of Nuclear Weapons.
6	ARL/R4/C791 Sept. 1957	Secret	Operation Mosaic. Final Report on Naval Measurements.
7	Air Ministry Science 2. Memo 270 (1957)	Confidential	Target Coverage by a Number of Nuclear Weapons.

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DAMAGE TO TARGETS IN GENERAL: Blast

No.	Originator and Reference	Security Classification	Title
7	A.F.S.W.P. Report ITR-1408 6th December, 1957, (M.O.D. Ref.No.378).	Confidential/ Discreet	Operation Plumbbob, Project 1.8b, Preliminary Report, Effects of Rough Terrain on Drag-Sensitive Targets.
8	Armour Research Foundation Project MO.24-1	Confidential/ Discreet	Final Report No. 18, 1954.
9	A.F.S.W.P. Report WT-1168	Official Use Only	Operation Teapot, Project 33.4. Distribution and Density of Missiles from Nuclear Explosions.
10	A.F.S.W.P. Report ITR-1469	Official Use Only	Operation Plumbbob, Project 33.3. Tertiary Effects of Blast-Displacement.

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No.	Originator and Reference	Security Classification	Title
1	ARDE Report (B24/57)	Confidential/ Discreet	A Unified Theory of Damage from Minor External Blast. Thornhill.
2	ARDE Memo. (S18/57)	Secret/ U.K.Eyes Only	Models and Targets to be Employed in 'L' Lane on Operation Buffalo. Laing.
3	Proc.Roy.Soc.(A) Vol.1226 No.311. 20.8.57.	Unclassified	Studies in Collapse Analysis of Rigid/Plastic Plates with a Square Yield Diagram. Mansfield (Royal Aircraft Establishment).
4	"Nature", October, 1957 Vol. 180 No.4588, p.702	Unclassified	Aerodynamic Drag of Perforated Plates. Letter from Francis and Minton (Imperial College).
5	Home Office Civil Defence Structural Precautions Research Committee Paper CD/SPR/137 (1954)	Secret	Blockage of Roads and Open Spaces by Debris caused by a 20 KT Bomb.
6	A.W.R.E. Report E6/55	Secret/Atomic/ Discreet (C.C.)	Estimates of Some Blast Wind Effects of Megaton Bombs.
7	Nature, Vol.181, No.4613, p.873, 29th March, 1958	Unclassified	Damage to Solids by Liquid Impact at Supersonic Speeds. Bowden and Brunton.
8	Armament Research & Dev. Estab. A.R.D.E. Memo. 29/59	Confidential	Models and Target Response Scaling Laws. G.J. Laing.
9	AORG Memo. F.15 Oct. 1955	Secret	Protection Afforded by Terrain Against the Effects of Nuclear Explosions.

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DAMAGE TO TARGETS IN GENERAL: Thermal Radiation Damage and Fire Storms

No.	Originator and Reference	Security Classification	Title
1	U.S.A.Department of Agriculture Report AFSWP-413. Home Office Ref. CD.7384. (M.O.D.Ref. No.26).	Unclassified	Primary Ignitions following Atomic Attack on Urban Targets (Transient Exterior Fuels. 1953).
2	U.S.A. Department of Agriculture, Report AFSWP-412. Home Office Ref. CD.7385. (M.O.D.Ref. No.28).	Unclassified	Distribution of Primary Ignition Points following Attack on Urban Targets. (Transient Exterior Fuels. 1953).
3	U.S. Naval Radiological Defence Laboratory Paper No. 14 for 1957 Tripartite Conference.	Unclassified	Ignition of Combustible Materials. Plum.
4	U.S. Forest Services. (M.O.D.Ref. No. 24)	Unclassified	Fire - Progress Report No. 2 (1954). A Study of Mass-Fire Build-up.
5	U.S. Forest Services. (M.O.D.Ref. No.25)	Unclassified	Fire. Progress Report No. 1, 1954.
6	U.S. Department of Agriculture, 20th January 1952,(M.O.D. Ref.No.94).	Confidential/ Discreet	Burning Potential - Forest and Wild Land Areas. Department of Fire Research Report to O.R.O. Johns Hopkins University.
7	A.F.S.W.P. Report WT-774 (M.O.D.Ref.No.77).	Confidential/ Atomic	Operation Upshot-Knothole, Project 8.11A, Incendiary Effects of Building and Interior Kindling Fuels, 1953.

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No.	Originator and Reference	Security Classification	Title
8	U.S. Department of Agriculture Forest Service Forest Products Laboratory Wisconsin. Manual AFSWP-700	Confidential/ Atomic	Thermal Data Handbook - Sanitized Edition.
9	U.S.N.R.D.L.Report TR-101, 11th August,1955, T.I.L. Reference P.67803. Acsil Ref.57/3418.	Unclassified	Thermal Vulnerability of Military Installations.

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DAMAGE TO TARGETS IN GENERAL: Thermal Radiation Damage and Fire Storms

No.	Originator and Reference	Security Classification	Title
1	S.A. Br. Home Office CD/SA6 (CD/3090)	Secret	The Atomic Bomb as A Fire Raiser. A study of the Mechanism of Initiation and Development.
2	M. of Supply, A.R.D.E. BM/B/1/2/55	Confidential	The Theory of Thermal Explosions: the Initiation of Explosion by High Intensity Thermal Radiation.
3	S.A.Home Office CD.1628	Secret	Some thoughts on the Fire Problem from Atomic Bombs.
4	S.A.Home Office CD/SA10 CD.2176	Secret	The Fire Risk Attendant on the Use of Black-out Curtains during an Atomic Bomb Attack.
5	Min. of Home Security REN.567 (CD.2952A)	Restricted	Investigation of Fire Damage Caused by Atomic Bombs at Nagasaki and Hiroshima (Jan.1950).
6	Tripartite Conference on C.B. and R.W. 9th Porton (DRB.54/10123)	Secret	Service Aspects, Item 5. Protection against Atomic Attack by Dispersion of Ships and the use of Smoke to Diffuse Thermal Effects.
7	DSIR/FOC Joint Fire Res. Orgn.Special Report No.2 (CD 6076)	Unclassified	Heat Transfer by Radiation (1953).
8	Joint Fire Research Organisation, S.R.Note 28/1956	Confidential	Heat Radiation Shelters for Defence against Atomic Explosions. Simms, Hinkley and Weston.
9	A.R.E. Report 1/48 Pt.20	Secret	The Physical Effects of Atomic Bombs. The Risk of Fires from Fractured Oil Tanks and Pipe Lines by Radiation Heating from an Atomic Bomb.

No.	Originator and Reference	Security Classification	Title
9	Chemical Corps Chemical and Radiological Laboratories Report CRLR-326, 15th September, 1955, (M.O.D.Ref.No.82).	Confidential/ Discreet (C.C.)	Experimental-Theoretical Attenuation of 1.2 Mev. Gamma Radiation by Simple Structures.
10	Chemical Corps Chemical and Radiological Laboratories Report CRLR-297, 1st August, 1953, (M.O.D.Ref.No.83).	Confidential/ Discreet (C.C.)	Attenuation of 1.2 Mev. Gamma Radiation by Soviet and U.S. Military Vehicles and U.S. Rail Equipment.
11	Naval Research Laboratories Report NRL 4581 of 26th July, 1955 (M.O.D.Ref.No.149)	Discreet	Penetration of Na 24 Radiation through H_2O and Hg.
12	National Bureau of Standards Report NBS.2902 of 8th October, 1954 (M.O.D.Ref.No.152)	Unclassified	The Dose received by Partially Shielded Gamma Ray Detectors.
13	Naval Research Laboratory Report NRL-4666, 7th December, 1955 (M.O.D. Ref. No. 183).	Unclassified	Total Cross Sections for 14 Mev. Neutrons, and Comparison of Measured Values with Values calculated from the Complex Square-Well Model.

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DAMAGE TO TARGETS IN GENERAL : Nuclear Radiation, Contamination and Decontamination

No.	Originator and Reference	Security Classification	Title
14	U.S.N.R.D.L. Report TR-31 (Contract NY-320-001), 14th January, 1955 (M.O.D.Ref.No.362).	Unclassified	Buffer Zones required in the reclamation of Radiologically Contaminated Areas.
15	U.S.N.R.D.L. Report AD-322 (March, 1952) (M.O.D.Ref.No.364)	Unclassified	Report of Land Reclamation Tests.
16	A.F.S.W.P. Report No. WT-400	Confidential	Operation Jangle, Project 6.2, Protection and Decontamination of Land Targets and Vehicles.
17	Tech. Command Interim Report No. 627 Project 4-12-07-001 Feb. 1951	Confidential	The Proper Role of Detergents in Relation to Radiological Decontamination. Levin.
18	U.S. Society of Mech.Eng. Report 57-SA-52 June 1957	Unclassified	An Engineering Approach to Radiological Decontamination. M.B. Hawkins.
19	USN/RDL Report AD-220(T) May 1950	Unclassified	Field Factors Affecting Contamination. Stetson et al.

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No.	Originator and Reference	Security Classification	Title
1	Tenth Tripartite Conf. on Toxicological Warfare A.E.R.E. EL/R.1798, p.46	Secret	A Report on the Meetings on Radiological Defence.
2	R.A.E. Library Bibliography No. 195.	Unclassified	List of (Unclassified) References on Atomic, Photon, and Ion Propulsion of Aircraft; the Shielding of Aircraft Nuclear Reactors; the Medical Hazards of Atomic Powered Aircraft; and the Effect of Atomic Radiation on Aircraft Materials and Components.
3	1957 Tripartite Conf. A.W.R.E. Report O-35/56(X)	Official Use Only	Dose rates from Ground Contaminated with Residual Radioactive Materials from an Atomic Explosion.
4	A.W.R.E. Report O.49/55	Official Use Only	A Guide to Radiological Decontamination after a Nuclear Explosion or Radiological Attack.
5	A.W.R.E. Report T.22/57	Confidential	Operation Buffalo. Decontamination Group Report, Parts 1-4.
6	C.D.E.E. Porton Tech. Paper (R)15, Sept. 1958.	Restricted	Radiological Decontamination: an Investigation of the Absorption of Fission Isotopes into Concrete. H. Stretch.

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PERSONNEL, ANIMALS, AND VEGETATION: Damage by Combined Effects.

No.	Originator and Reference	Security Classification	Title
1	B.N.M.L.O. Washington /3 13th Aug. 1954	Restricted U.K. Eyes Only	Medical Aspects of Atomic Warfare.
2	Tufts College. Inst. for App.Exp.Psychology and U.S.N. Special Devices Centre. Nav Eos P-643 ACSIL/50/1938 TIB No. P.50584	Unclassified	Handbook of Human Engineering Data, 2nd Edition (Revised), 1.11.1952.
3	Operations Res. Office Report ORO-T-1 (Conarc). CORG-FER-1 (M.O.D.Ref. Nos. 265 and 266)	Secret/Atomic	Vulnerability of The Infantry Rifle Co. to the Effects of Atomic Weapons: (A study of a week's Infantry manoeuvres). Parts I and II.
4	A.F.S.W.P. Report 602 (M.O.D. Ref. No. 115)	Secret/Discreet	A Study of the Influence of a Forest on the Effects of an Atomic Weapon (1953).
5	Department of Forest Fire Research. Letter dated 13th July, 1954. (M.O.D. Ref. No. 116)	Confidential/ Discreet	Letter from U.S. Department of Agriculture to A.F.S.W.P. forwarding the draft Isodamage Curves for three types of Forest Stand, for use in "Capabilities of Atomic Weapons".
6	U.S.A.E.C. Paper Wash. 545, 1955 (M.O.D.Ref.Nos. 144 and 191)		Tripartite Discussions on Effects of Atomic Weapons on Human Beings and their Environment, 14th April, 1955. Subjects include Effects of Induced Radiation, Pressures, Times to Minimum, Cratering, Burns, and the Effects of Fallout on Certain Marshallese Islanders.

No.	Originator and Reference	Security Classification	Title
7	British Naval and Army Medical Liaison Officer, Bureau of Medicine and Surgery, Washington. BNAMLO/19, 14th September, 1956 (M.O.D.Ref.No. 240)	Unclassified	Management of Mass Casualties. Report of 5½ day Course at Walter Reed Army Institute for Research, 20th-25th August, 1956.
8	U.S. Government Printing Office, 1956.	Unclassified	Medical Effects of Atomic Bombs in Japan. Oughterson and Warren.
9	Tripartite Conference, 1954.	Secret/ U.K.Eyes Only	Biological Effects of Atomic Weapons.
10	J.Amer.Med.Assoc., Vol.34, pp.1143-8, 1947	Unclassified	Medical Sequelae of Atomic Bomb Explosions. Le Ray.
11	J.Amer.Med.Assoc., Vol. 147, pp.858-862, October, 1951.	Unclassified	Nature of Air Raid Casualties. Enloc.
12	J. Maine Med. Assoc., Vol.41, pp.144-159(1950).	Unclassified	What Every Doctor should know: Medical Aspects of Atomic Weapons.
13	Med. Clinics, N.Amer., Vol.36, pp.263-272 (1952) (Available in M.R.C. Library).	Unclassified	The Physician in Atomic Defence. Sears.
14	U.S.F.C.D.A.	Unclassified	Civil Defence Reading List.

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No.	Originator and Reference	Security Classification	Title
1	Home Office (CD.9582)	Secret/U.K. Eyes	Casualty Rates for Ground Burst 10 Megaton Bombs, October, 1956.
2	A.W.R.E. T18/57	Confidential	Operation Buffalo: Target Response, Interim Report, Biology Group.
3	A.W.R.E. T18/54	Official use only	Hurricane Part 43. Trial carried out for Ministry of Food.
4	A.W.R.E. T44/54	Confidential	Summary Report on Biological Experiments.
5	D.T.S.D. Admiralty Part III of "Atomic Bomb Trials" (Op.Crossroads) CD.2122.	Top Secret	Biological Effects in the Bikini Atomic Bomb Trials.
6	A.O.R.G. Memo E.1.		Ready Reckoner for Atomic Casualties.
7	B.A.O.R. Operational Research Section Report 3/56.	Confidential	Effects of Atomic Weapons on Forests in North West Europe.
8	A .O.R.G. Report No.12/55	Secret/U.K. Eyes Only	The Protective Value to Personnel of Slit Trenches against Thermal and Gamma Radiation Effects of Nuclear Explosions.
9	Nelson, 1949.	Unclassified	Atomic Medicine. Behrens (Book)
10	Admiralty, 1955.	Unclassified	Course on Atomic Energy for Medical Officers
11	Home Office, H.M.S.O.	Unclassified	The H Bomb (Pamphlet).
12	War Office Code No. 11934 26/Manuals/3859 April, 1957.	Restricted	Notes on Nuclear Warfare for Medical Officers

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PERSONNEL, ANIMALS AND VEGETATION: Thermal Radiation, Burns, Flash Blindness

No.	Originator and Reference	Security Classification	Title
23	Reprint from "Surgery" December, 1956, Vol. 103 p. 655/665	Unclassified	Flash Burns from Atomic Weapons. Butterfield, et al.
24	Volume I (1942) and Volume VI (1954)	Unclassified	Text book of Ophthalmology. Duke - Elder.
25	Surgical Progress. Butterworth, London, 1951.	Unclassified	Pages 132-145. Burns, Flash, Butterfield, W.J.H.
26	A.W.R.E. Report T. 11/58	Confidential	Operation Buffalo. Target Response Tests, Materials Group, Part 6. The Effects of Thermal Radiation from a Nuclear Explosion on Service Uniforms.
27	R.A.E. Technical Note ME. 274.	Secret/Discreet	Visual Incapacitation of Aircrew by Nuclear Anti-Aircraft Weapons. Brinkworth.
28	Brit. J. Phys. Med., May, 1931	Unclassified	Penetration of Radiation into Animal Tissue. Pearson and Gair.
29	E.R. Drake-Seager, S.A.B./T.G. (58)2, Amended	Secret	Report on Visit to North America, 1956. Canadian Section.
30	AORG Report 18/58 Nov. 1958.	Confidential	The Tactical Implications of Flash Blindness and Chorioretinal Burns Caused by Nuclear Explosions. Part 1 Flash Blindness. E. G. Smith.
31	M.O.S., M.X.5 Report 8/55	Restricted	Experimental Methods of Flash Burning. (An Account of a Visit to Rochester University, New York). Blease

No.	Originator and Reference	Security Classification	Title
31	U.S.N.R.D.L. Report TR-47 2nd May, 1955. (M.O.D. Ref. No. 157.)	Confidential/ Discreet	Effectiveness Specifications for Radiological Defence Countermeasures. Defines Degree of Decontamination required in various Circumstances.
32	U.S.A.E.C. Paper HW-27620 16th February, 1953, (M.O.D. Ref. No. 171.)	Unclassified	The Uptake of Fission Fallout Material by Plants and Animals. U.S.A.E.C. Hanford, Atomic Products Operation, Biology Section Metabolism Unit Report entitled "The Absorption and Translocation by Plants of Radioactive Elements from 'Jangle' Soil".
33	A.E.C./O.R.N.L. Report AECU-2332, 4th April, 1952	Unclassified	External and Internal Exposure to Ionising Radiation and Maximum Permissible Concentration (M.P.C.) of Radioactive Contamination in Air and Water following an Atomic Explosion.
34	U.S.A.E.C. Greenhouse Programme 2 Report WT-2 (M.O.D. Ref. 268.)	Official Use Only	Operation Greenhouse, Scientific Director's Report, Annexe 2.1, Japtan Island. Development and Animal Production, Part I - Facilities, and Part II - Animal Colony. Fredric Flader Incorporated Report NEPA-624-FF-13, 31st January, 1948, (M.O.D. Ref. No. 283.)
35	University of California, Los Angeles School of Medicine, Report ITR-1177, August, 1955, (M.O.D. Ref. No. 283.)	Confidential/ Atomic	Operation Teapot, Project 37.1. Preliminary Report: The Factors influencing the Biological Fate and Persistence of Radioactive Fallout.
36	Army Chemical Centre, Chemical Warfare Laboratories Paper 11 Tri-C.88, August 1956. (M.O.D. Ref. No. 305.)	Confidential/ Discreet	Eleventh Tripartite Conference on Toxicological Warfare. U.S. Progress Report on Radiological Defence, 1st July, 1955 to 30th June, 1956.

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No.	Originator and Reference	Security Classification	Title
37	Oakridge National Laboratory Report ORNL-2304, 11th June, 1957, (M.O.D. Ref. No. 328.)	Unclassified	Health Safety. A Study of the Distribution and Examination of Uranium in Man - An Interim Report.
38	U.S.N.R.D.L./Commander, Task Group 7.3 Report WT-1012, 8th May, 1957, (M.O.D. Ref. No. 340).	Official Use Only	Operation Wigwam, Project 2.4. Final Report, superseding ITR-1012.
39	U.S.N.R.D.L. Report AD-145 (L) (Series D), 9th August, 1949, (M.O.D. Ref. No. 365.)	Unclassified	Training Industrial Personnel in Radiological Safety (Lecture, August, 1949).
40	Nucleonics, Vol. 10, p. 18 (1952).	Unclassified	Delayed Radiation Effects of Hiroshima and Nagasaki. Bugher.
41	An. Int. Med., Vol. 36, p. 279 (1952).	Unclassified	The Acute Radiation Syndrome. A Study of Nine Cases and a Review of the Problem. Hempelmann et al.
42	National Nuclear Energy Series, Division 8, Vol. 8, McGraw Hill Book Co., New York, 1956.	Unclassified	Medical Effects of the Atomic Bomb in Japan. Ed. Oughterson and Warren.
43	Science, Vol. 122, No. 3181, p. 1178 (1955).	Unclassified	Radioactive Fallout in the Marshall Islands.
44	J. Amer. Med. Assoc., Vol. 159, p. 430, 1955.	Unclassified	The Response of Human Beings Accidentally Exposed to Significant Fallout Radiation. Cronkite et al.

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No.	Originator and Reference	Security Classification	Title
1	A.W.R.E. T11/57	Official Use Only	Operation Buffalo: The Dose Received at Various Parts of the Body by a Man Walking over Contaminated Ground.
2	Air Ministry Sc.2 Memo. 254	Top Secret Atomic U.K.E.O.	The Danger to Bombers from Radio-active Clouds over a Realistic Target Area.
3	Atomic Scientists Journal Vol.4, No.2, Nov.1954	Unclassified	Bikini Ash
4	Home Office (CD.7241)	Confidential U.K.Eyes Only	The Initial Gamma Radiation Hazard from Very Large Weapons.
5	M of Supply, A.E.R.E. (Feb.1952) HP/M31	Confidential	Estimation of Energy Tolerances for Fission Products in Air and Water.
6	M of Supply, A.E.R.E. HP/M23	Confidential	Energy Tolerance for Fission Products in Drinking Water.
7	The Listener 28th October, 1954	Unclassified	The Dangers of Radioactive Dust.
8	A.R.Laboratory (Jan.1950) Report N1/R.322	Secret/Discreet	Effect of Continued Exposure to Radiation from Decaying Fission Products.
9	A.E.R.E./H.O. HP/R/737 (CD/SA/23)	Unclassified	The Hazard from Inhaled Fission Products in Rescue Operations.
10	M of Supply A.R.E.(1948) A.R.E. Report 1/48	Secret	Part 3. Gamma Deaths from an Open Window.

No.	Originator and Reference	Security Classification	Title
11	Medical Research Council P.A.B.E. Report No. 11	Secret	Hazards of Radioactive Dust.
12	A.W.R.E. O-23/54	Secret	Decontamination of Clothing II. Laundry Investigations and Recommendations.
13	A.W.R.E. O-22/54	Secret	Decontamination of Clothing I. Laboratory Investigations.
14	"Nucleonics" 12/1954 No. 9, 39.	Unclassified	Evaluating Reactor Hazards from Airborne Fission Products.
15	A.E.R.E. HP/R.1495	Unclassified	Derivation of Maximum Permissible Levels of Contamination of Surfaces by Radioactive Materials.
16	A.E.R.E. Report EL-R.1798	Secret	10th Tripartite Conference on Toxicological Warfare. A Report on the Meetings on Radiological Defence. Taylor.
17	British Journal of Radiology. Supplement No.6, 1955.	Unclassified	Recommendations of the International Commission on Radiological Protection, 1955.
18	Home Office	Restricted	Report of a Home Office Committee on the Ventilation of Protected Accommodation under Fallout Conditions.
19	Brit. J. Indus. Med. Vol.9, No.2, April, 1952	Unclassified	Dust Sampling and Lung Diseases. Davies.
20	Agricultural Res. Cttee. AERE Report ARC/RBC.5	Official Use Only	Ingestion of Fallout by Grazing Animals. Scott Russel, et al.

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No.	Originator and Reference	Security Classification	Title
21	"Nature", Vol. 177 No. 4513, p. 787, 28.4.56.	Unclassified	Genetic Effect of X-rays in relation to Dose Rate in Drosophila. Clark.
22	R.A.E. Library, Bibliography No. 195	Unclassified	List of (Unclassified) References on Atomic, Photon and Ion Propulsion of Aircraft; the Shielding of Aircraft nuclear reactors; the Medical Hazards of Atomic Powered Aircraft; and the Effect of Atomic Radiation on Aircraft Materials and Components.
23	A.W.R.E. Report O. 34/56	Official Use Only	The Ingestion of Food contaminated by Atomic Explosions.
24	A.W.R.E. Report T. 65/57	Confidential	Operation Buffalo. Biology Group, Part IV(b), The Effects of Neutron and Gamma Irradiation upon Foodstuffs.
25	Medical Research Council H.M.S.O. Cmd. 9780, June, 1956.	Unclassified	The Hazards to Man of Nuclear and Allied Radiations.
26	A.W.R.E. Report T4/57	Confidential	Decontamination of Radioactively Contaminated Drinking Water in the Field.
27	R.A.E. Tech. Memo. ARM/1728	Secret	Incapacitation of Aircrew by Irradiation.
28	Ministry of Supply, D.A.W. Plans Memo. XY/144/03	Secret	Capabilities of Aircrew after Irrediation by Counter-Weapons (Equipment Considerations).
29	A.W.R.E. Report H12/52	Official Use Only	The Penetration of Gamma Radiation through the Walls of a Slit Trench.
30	M.R.C./A.E.R.E. 1955		The Effects of Gamma on Animals. Loutit.

No.	Originator and Reference	Security Classification	Title
31	Nature, Vol. 182, No. 4648, pp. 1473-1478, 29th November, 1958.	Unclassified	Radioactivity due to Fission Products in Biological Material. Article by Mayneord et al.
32	A.E.R.E. Paper HP/R 1677	Official Use Only	European Atomic Energy Society Symposium of Nuclear Reactors, 23rd-24th March, 1955. Chamberlain.
33	Nature, Vol. 182, No. 4652, pp. 1787 1790	Unclassified	A. Radiobiochemical Lesion in Animal Cells (Survey Article by Ord and Stocken). B. Magnitude of Radiation Effect on the Process of Synthesis of Deoxyribonucleic Acid. Lajtha et al.
34	A.E.R.E. Report AERE EL/R 1798, 1955. (M.O.D. Ref. No. 180)	Secret	Tenth Tripartite Conference on Toxicological Warfare (1955).
35	A.E.R.E. Paper AERE EL/R 2118, (M.O.D. Ref.No. 281)	Secret	Eleventh Tripartite Conference on Toxicological Warfare. Report on the Meetings on Radiological Defence, 1956. (Includes also Thermal Burn and Flash Blindness Data).
36	A.W.R.E. Report TCR 25/57 September, 1957. (M.O.D. No. 390)	Secret U.K. Eyes Only	Twelfth Tripartite Conference on Toxicological Warfare. a Report on the Meetings on Radiological Defence.
37	A.W.R.E. Report T54/57.	Confidential	The Hazards to Air Crew Flying through an Atomic Cloud.
38	Tripartite Conf. Nov. 1955 Paper TC6/55	Unclassified	Radiation Sickness in Man and Monkey. Loutit.

No.	Originator and Reference	Security Classification	Title
39	C.D.E.E. Porton Tech. Paper (R)16 Nov. 1958.	Confidential	Radiological Decontamination: Removal of Dry Fallout from Skin and Clothing. E. Neale and Elizabeth H. Letts.
40	13th Tripartite Tox. Conf. Sept. 1958. Admiralty Paper DPR/BWS/144/58	Confidential	Contamination by Radioactive Fission Products. Acceptable Levels of Personal Contamination under Exceptional Circumstances. B. W. Soole.
41	ARL/N4/0775 Dec. 1958	Unclassified	Manufacturing Specification for ARL Radiological Barrier Cream Type P.2. E. W. Jackson.
42	Nature Vol.182 pp. 1118-9 (Oct. 25th 1958)	Unclassified	Summary of Second U.N. Geneva Conference Proceedings Relating to the Biological Effects of Radiation. J. F. Loutit.
43	H.Pan/S.23 Dec. 1957.	Official Use Only	Treatment of Personal Radioactivity Contamination. An Outline of the Practice in the U.K.A.E.A. J. B. Lynch.
44	Atomic Energy Research Estab. Report AERE-L.101 (2nd Edition of AERE Report HP/L23) March, 1959.	Unclassified	A Short Course in Radiological Protection Editor R. J. Sherwood
45	War Office Paper 70/Nuclear/61, (GS(W).11) March, 1959. Also ARL/R 867.14.	Confidential	The Beta Dose to the Infantryman's Head. Maj. W. T. M. Gaskell.

No.	Originator and Reference	Security Classification	Title
46	A/Conf. 15/P/2324	Confidential	2nd U.N. Conference. Observation on Recovery and Irreversible Radiation Injury in Mammals. Hursh. et al.
47	Nature Vol. 180 p. 1466 (Dec. 28th 1957)	Unclassified	The General Radiation Syndrome: Initial Reaction in the Monkey. (Letter by C. G. Hunter et al)
48	13th Tripartite Tox. Conf. September, 1958 U.K. Paper	Confidential	Acceptable Levels of Water Contamination.
49	13th Tripartite Tox. Conf. Sept. 1958 U.K. Paper	Confidential	Contamination of Body Surfaces and Personal Equipment by Radioactive Material.
50	13th Tripartite Tox. Conf. Sept. 1958. Admiralty Paper DPR/BWS/143/58	Confidential	A Comparison of the Internal and External Radiation Hazards to a Man Exposed to a Cloud of Fission Products from a Nuclear Explosion. B. W. Soole.
51	13th Trip. Conf. on Tox. Warfare Paper TCR7/58	Confidential	The relative Importance of External and Inhalation Hazards to Personnel in Fallout Areas and in Aircraft. J. K. Jones.
52	13th Trip, Conf. on Tox. Warfare Paper TCR2/58.	Confidential	Suggested Wartime Doses of Ionizing Radiation for Home Defence Purposes. Stanbury.
53	Tripartite Conf. Nov. 1955 Paper TC7/55	Unclassified	Contamination of Wounds with Fallout from Nuclear Weapons. Barnes and Loutit.

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No.	Originator and Reference	Security Classification	Title
54	Medical Research Council Report PABE/100 Feb. 1957.	Official Use Only	Review of Maximum Permissible Levels of Fallout Contamination for Food and Drinking Water G. J. Neary.
55	T.C.R. 9/58 Feb. 1959	Secret U.K. Eyes Only	13th Tripartite Conference on Toxicological Warfare. A Report of the Meetings on Radiological Defence. Barnes, Stanbury and Abson
56	Res. & Dev. Branch U.K.A.E.A. Risley RGL-IB/R21 1957.	Unclassified	Information Bibliography. General Health Physics.
57	12th Tri. Conf. on Tox. Warfare Paper TCR20/57	Confidential	Decontamination of Personnel and Equipment - Techniques and Equipment Catherall and Stevenson
58	12th Tri. Conf. on Tox. Warfare U.K. Paper	Restricted	The Operational Aspects of Radiological Decontamination of Personnel. D. B. Janisch
59	ARL/R1/C775 July 1957	Unclassified	Decontamination Experiments on Human and Animal Skin. E. W. Jackson
60	ARL/N2/C763	Unclassified	Techniques for the Decontamination of Ships and Personnel. Jackson.
61	A.E.R.E. Report EL/R2118	Secret	11th Tripartite Conference on Toxicological Warfare - A Report of the Meetings on Radiological Defence Barnes and Taylor.

No.	Originator and Reference	Security Classification	Title
62	ARL/N2/C775 June 1956	Unclassified	Decontamination of Personnel - Use of Hand Held Spray
63	Home Office Report CD/SA61 May, 1955	Secret	Neptunium as a Residual Radiation Hazard
64	AERE Report HP/R551 Aug. 1950	Unclassified	Estimation of Maximum Permissible Levels of Radiation
65	AERE Report HP/R731 Jan. 1951	Confidential	The Problem of Airborne Radioactive Dust in Atomic Energy Work. Proceedings of a Symposium Held at A.E.R.E. January 17th, 1951.
66	AERE Report HP/M101 March, 1956	Official Use Only	The Transportation of Radioactive Materials.
67	DSIR Water Pollution Res. Lab. Report No. 8 Nov. 1955	Secret	The Removal of Radioactive Iodine from Water by Passage through Silvered Kieselzuhr
68	ARL/N1/C775 Nov. 1955	Confidential	Evaluation of an Experimental Personnel Cleansing Booth. Jackson
69	A.W.R.E. Report T57/58	Unclassified	Operation Buffalo. Biology Group. Part 5. The Entry of Fission Products Into Food Chains.

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No.	Originator and Reference	Security Classification	Title
70	AERE Report HP/R2730 Nov. 1958	Unclassified	Radio Strontium in Soil, Herbage, Animal Bone and Milk Samples from the U.K. 1957 Results. F. J. Bryant et al.
71	M.O.S. C.D.E.E. Porton Note. No. 70 Jan. 1959	Secret	Contact Hazards: The Pick-up of Contaminant on Crawling Over a Contaminated Grass Area.
72	Home Office Report CD/SA.71	Confidential	Numbers of Casualties from a Ground Burst Megaton Weapon Likely to be Personally Contaminated by Radioactive Material. E. C. Allen
73	AERE Report HP/M108	Official Use Only	Radio-Strontium Fallout in Soil, Plant and Bone up to December, 1955.

No.	Originator and Reference	Security Classification	Title
1	A.W.R.E. Report T32/57	Confidential	Operation Buffalo: Interim Report, Target Response, Materials Group.
2	A.W.R.E. Report T77/54	Confidential	Effects on Respirators, Anti-gas.
3	A.W.R.E. Report T5/57	Confidential	Operation Buffalo: Interim Report, Target Response, Explosive Group.
4	M.O.S.S./AT/3 9 June 1957.	Confidential/ Atomic	Effects of Atomic Explosions on Conventional Explosives, Propellants and Initiators. Record of Discussion at O.C.O. on 19th November, 1956. Lewis E.G.
5	A.R.D.E. Memo (B) 1/58	Confidential	The Effects of Atomic Weapons on Ammunition. 1. Unguided Rockets, Litton J.C.
6	E.R.D.E. Report 9/R/58	Confidential/ Discreet	Operation Buffalo: The Effects on Propellants of Exposure to an Atomic Weapon Explosion. Cole L.D.
7	A.W.R.E. Report T5/58	Confidential	Operation Buffalo: Materials Group. Part 8A. Effects of a Nuclear Explosion on Petrol Pipe-Lines.
8	A.W.R.E. Report T7/58	Confidential	Operation Buffalo: Explosives Group, Final Report Part 1. Introduction.
9	A.W.R.E. Report T10/58	Confidential	Operation Buffalo. Materials Group, Part 8B. The Effect of a Nuclear Explosion on Jerrican Stacks.
10	A.W.R.E. Report T17/58	Confidential	Operation Buffalo: Target Response Tests, Materials Group. Part 1 - General Introduction.
11	A.W.R.E. Report T64/57	Confidential	Operation Buffalo. Effects of an Atomic Explosion on Medical Supplies.

U.S. Reports. DAMAGE TO MATERIALS: Damage by Combined Effects

No.	Originator and Reference	Security Classification	Title
1	A.F.S.W.P. Report WT-1216 (M.O.D. Ref. No. 332)	Unclassified	Operation Teapot: Project 32.3. The Effect of Nuclear Explosions on Meat and Meat Products.
2	A.F.S.W.P. Report WT-1215 (M.O.D. Ref. No. 333)	Unclassified	Operation Teapot: Project 32.5. Effects of Nuclear Explosions on Frozen Foods (1955).
3	A.F.S.W.P. Report WT-1214 (M.O.D. Ref. No. 334)	Unclassified	Operation Teapot: Project 32.4. The Effect of Nuclear Explosions on Semi-perishable Foods and Food Packaging (1955).
4	A.F.S.W.P. Report WT-1213 (M.O.D. Ref. No. 335)	Unclassified	Operation Teapot: Project 32.2(a). The Effect of Nuclear Explosions on Commercial Packaged Beverages (1955)
5	A.F.S.W.P. Report WT-1163 (M.O.D. Ref. No. 336)	Unclassified	Operation Teapot: Project 32.1. Effects of Nuclear Explosions on Bulk Food Staples (1955).
6	A.F.S.W.P. Report WT-1212	Official Use only	Operation Teapot: Project 32.2. Effects of Nuclear Explosions on Canned Foods.
7	A.F.S.W.P. Report WT-1222	Official Use only	Operation Teapot: Project 32. Exposure of Foods and Food Stuffs to Nuclear Explosions (A Summary of Results).

No.	Originator and Reference	Security Classification	Title
1	Air Ministry Sc. 2 Memo. 254	Top Secret Atomic U.K.E.O.	The Danger to Bombers from Radio-Active Clouds over a Realistic Target Area.
2	A.W.R.E. T106/54	Secret	The Prevention and Removal of Radioactive Contamination, Part VI. Decontamination of Aircraft, and Health Control at Woomera and Amberley.
3	Admiralty TIB(BR)50	Secret	A Report on the Radiological Decontamination of Aircraft.
4	Royal Aircraft Est. Library Bibliography No. 195.	Unclassified	List of (unclassified) References on Atomic, Photon, and Ion Propulsion of Aircraft; the Shielding of Aircraft Nuclear Reactors; the Medical Hazards of Atomic Powered Aircraft; and the Effect of Atomic Radiation on Aircraft Materials and Components.
5	A.W.R.E. Report No. T63/57.	Official Use Only	The Handling, Servicing, and Decontamination of Radioactive Aircraft.
6	A.W.R.E. Report No. T33/57	Confidential	Operation Mosaic. Aircraft Decontamination.
7	Ministry of Supply, D.A.W.(Plans)Memo XY/98/05	Secret	Protection in Military Aircraft against the Products of Nuclear Fission.
8	Ministry of Supply, D.A.W.(Plans)Memo. XY/144/03.	Secret	Capability of Air Crew after Irradiation by Counter-weapons. (Equipment Considerations)
9	AP(N)123 1957	Restricted	Draft Handbook on the Radiological Decontamination of Aircraft.
10	Air Ministry Science 2. Memo 230 (1954)	Secret/ Atomic	The Danger to Bombers from Radioactive Clouds Over a Simplified Target Area.

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No.	Originator and Reference	Security Classification	Title
11	Air Ministry Science 2. Memo 272 (1957)	Secret	The Effect of Radioactive Fallout on the Operation of Fighter Airfields.

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No.	Originator and Reference	Security Classification	Title
1	U.S.Naval Radiological Defence Laboratory. Report U.S.N./R.D.L.-362. August 1952. (M.O.D.Ref. No. 267) (T.I.L. Ref. P.60499) ACSIL 5613913.	Confidential/ Discreet	Radiological Factors Affecting the Operation of Aircraft in Atomic Warfare. Progress Report prepared for the Bureau of Aeronautics, Part A. For Part B (Secret) see DRB 54/15494.
2	U.S.N./R.D.L. Report No. 447 (M.O.D. Ref. No. 113)	Confidential/ Discreet	Proposed interim Operational Plan for the Tactical Decontamination of Carrier-Based Aircraft.
3	Naval Medical Research Institute, Bethesda. Report ADC-54 Revised. 10 March 1949. (M.O.D.Ref. No. 216)	Unclassified	Survey of Decontamination. 2 - Decontaminability of Aircraft Paints.
4	Wright Air Development Centre. Materials Lab. Report W.C.R.T.H.-M-5569. (M.O.D. Ref. Nos. 259 & 260)	Secret/ Discreet	Decontamination of Aircraft in Operation Buster.
5	Wright Air Development Centre. A.F.S.W.P.Report WT-535. March 1953. (M.O.D.Ref.Nos.261 & 262)	Confidential/ Discreet	Operation Snapper. Project 6.5. Decontamination of Aircraft.
6	U.S.A.F. Ref.AF-WP-O-15 T.O. No. 000-110A-3. 4th August 1952. (M.O.D. Ref.Nos. 263 & 264)	Discreet	Decontamination of Radio-Active Aircraft - External Surfaces. (1952)

No.	Originator and Reference	Security Classification	Title
1	Min. of Defence Tripartite Conference February, 1954. Section No. 4.	Secret/ U.K. Eyes Only	Thermal and Blast Effects on Aircraft
2	A.W.R.E. Report No.T28/58	Confidential	Operation Buffalo. Target Response Tests. Materials Group. Part 9C. Effects on Aircraft Wind Screens.
3	N.J.Hoff (Pergammon Press Ltd. London, 1958)	Unclassified	High Temperature Effects in Aircraft Structures. (Book)
4	RAE.Tech.Note. No. Mech. Eng.251.	Confidential	Skin Temperature Rise in an Aircraft Exposed to Thermal Radiation from a Nuclear Explosion. Brinkworth.
5	RAE Tech.Note. No. Mech.Eng.268.	Confidential	The Effects of Non Uniform Absorbtivity of Thermal Radiation from Nuclear Explosions on the Temperature rise in an Aircraft Skin. Brinkworth.
6	RAE.Tech.Memo. Arm 1726	Restricted	Notes on Radiation Reflected from a Plain Surface. Spring.
7	RAE.Test Note: Structures 1519	Confidential	Combined Transient Heating and Static Loading Tests of a Valiant Aileron. Naylor.
8	R.A.E. Report Mech.Eng. 21 21st Feb. 1959.	Confidential	Some Effects of the Environment on the Polar Distribution around the Delivering Aircraft of Thermal Radiation from a Nuclear Explosion. B. J. Brinkworth